ECOLOGICAL STUDIES OF THE BIOTA OF THE ALA WAI CANAL

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ABSTRACT

The Ala Wai Canal is a long, narrow, man-made estuary located in the Waikiki district of Honolulu, Hawaii. Because of its proximity to a densely populated urban resort area, it is of considerable interest as a recreational facility.

The present study of the Ala Wai Canal presents a detailed description of the physical-chemical parameters of temperature, oxygen, and salinity with regard to their horizontal, vertical, and seasonal distribution in the waters of the Canal. These parameters are in turn used to evaluate the distribution and species composition of the various marine organisms of recreational value and their associated food species.

The results of this study provide the baseline data for management recommendations to increase the recreational value of the Canal to the people of Hawaii.

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I. INTRODUCTION

A. Description of the Area

The Ala Wai Canal is a long, narrow, man-made estuary extending southeast by northwest. It separates the low-lying Waikiki district of Honolulu, Hawaii, from the Makiki-Manoa and Palolo drainage areas which encompass approximately 1.06×10^4 acres or $4.3 \times 10^7 m^2$ (Gonzalez, 1971). The Canal was originally dredged in 1927 by the Army Corps of Engineers as a marsh land reclamation project. It may be considered as geographically divisible into two sections. The outer entrance section extends from the northern border of the Ala Wai Yacht Harbor, specifically the Ala Moana bridge, approximately 750 m north to the Kalakaua Street bridge. At this point the Canal makes a 45-degree turn and widens from the previous 50 m width to 76 m as it enters the larger inner section, 2,350 m in length (Fig. 1). The Manoa-Palolo streams enter the Canal about midway in the inner section and are the major source of drainage effluent in the Canal. The mean depth of the Canal is approximately 2 m but varies considerably from this value in specific areas.

The Canal is of considerable interest to the State of Hawaii primarily due to its location directly adjacent to the resort section of Waikiki. Soon after its initial dredging, the Canal became a popular fishing and crabbing location for the local people. Esthetically, it was a pleasant body of water in the midst of the business district of Waikiki and numerous small boats were moored along the banks or cruised on the calm waters.

The evolutionary sequence of most estuaries is one of gradual accretion with soil from the surrounding land. The Canal is no exception and maintenance dredging has been required periodically over the past 45 years to remove accumulations of sediment. In addition to the "normal" silting one would expect as a result of local weather conditions, the Canal is occasionally subject to abnormal influxes of sediment from exposed graded areas associated with the major construction projects in the drainage basin. The high percentage of paved land area in the watershed encourages maximum runoff and consequent greater erosion of these graded areas. Unfortunately, the Canal also receives considerable trash and dissolved pollutants. Excessive nutrients in the latter promote an overabundance of phytoplankton which contributes greatly to the adverse visual appearance of the Canal.

The growing population of Oahu and the resultant need for an increase in land and recreational facilities has led to the present study to determine the prevailing physical and biological conditions in the Canal.

The results of this study will provide the basis for management recommendations to increase the recreational value of the Canal to the people of Hawaii.

B. Objectives: Ecological Studies of the Biota

The specific objectives of this study may be outlined as follows:

1. Physical Environmental Parameters

   To describe the horizontal, vertical and seasonal distribution of the physical environmental factors as they apply to organisms in the Canal.

2. Biological Environmental Parameters

   To describe the horizontal, vertical and seasonal distribution of organisms of recreational value and their associated food species.

3. Primary Productivity

   To investigate the total amount and variation with time of primary productivity.

4. Pesticides

   To determine the sources and quantity of pesticide residues in fish of recreational value.

The present report presents the results of objectives 1 and 2. Items 3 and 4 were previously completed as a University of Hawaii Masters Thesis by Carol Harris (see HIG report HIG-75-7) and Cynthia Shultz (see HIMB Technical Report 28), respectively.

II. METHODS AND INSTRUMENTATION

A. Collection Areas

1. Station Locations

   The numerous side streets about equidistant from one another and perpendicular to the Canal on the south or Waikiki side of the Canal served as reference marks for station locations. The 30 stations established in the Canal proper were directly opposite those streets or centered midway between widely spaced streets. Each station was therefore approximately the same distance (100 m) from its adjoining station. Unless otherwise noted, all collections were taken near the midline of the Canal. Stations 31-38 were evenly spaced from the confluence of the Manoa-Palolo streams and the Canal to the Date Street bridge, a distance of about 800 m (Fig. 1). These 38 stations were the reference locations for all collections.

2. Sections

The Canal was divided into four general sections to facilitate comparisons in the horizontal distribution of the physical and biological entities. The first section, stations 1-5, lies between the Ala Moana and Kalakaua Street bridges. The second section includes stations 6-17. The third section, stations 18-30, is the innermost section of the Canal, lying east of the confluence of the Manoa-Palolo streams. The fourth section, stations 31-38, is the stream proper, from the Date Street bridge south to the junction with the Canal.

B. Physical Measurements

Physical measurements consisted of values of salinity, temperature and oxygen at the surface and bottom as well as tide height, direction and depth of water. All physical measurements were conducted concurrently with the biological collections, as a basis for determining possible limiting effects of these parameters on the organisms present in the Canal.

1. Salinometer

Measurements of salinity were made in situ using a portable, battery-operated induction coil, Beckman RS-53 salinometer with a resolution of .01 $^{o}/oo$. Values were recorded to .1 $^{o}/oo$ as the reproducibility of a measurement to .01 $^{o}/oo$ under field conditions was questionable and considered not biologically significant. Measurements were taken at 20 cm below the surface and 20 cm above the bottom. Selection of these depths for measurement was based on the minimum of 20 cm of surrounding water required for accurate operation of the induction coil instrument.

2. Temperature Meter

Temperature measurements were taken concurrently with the salinity readings and with the same instrument, hence values were recorded at the same depths. Resolution was given to .01°C but recorded to .1°C for the field measurements.

3. Oxygen Meter

Oxygen was measured using a battery-powered Yellow Springs Model 54 portable Oxygen Meter. Measurements are in parts per million rather than the more usual ml/liter. Values were recorded to .1 ppm. For purposes of comparison, measurements of dissolved oxygen were made at the same depths and concurrently with the salinity and temperature measurements.

C. Biological Collections

Four major sampling devices have been used on a systematic basis over the period of this study: zooplankton nets, crab nets, otter trawls, and gill nets. With the exception of a few gill net sets, all sampling was conducted between the hours of 9:00 a.m. and 2:00 p.m.

1. Zooplankton Nets

Horizontal zooplankton tows using nets of three mesh sizes, 333μ, 250μ, and 64μ, were examined for species caught, number of individuals, clogging and ease of handling. On the basis of the preliminary test tows, it was concluded that the 333μ net has too large a mesh for the bulk of the canal zooplankton and was therefore inadequate for our use. The 64μ net suffered from the reverse problem. The quantity of phytoplankton, zooplankton and detrital material encountered in even a brief horizontal tow, i.e., 30 seconds, resulted in a totally clogged net. Hence it was concluded that the 250μ net would be most useful in describing the species present and their relative abundance. The majority of the horizontal collections were taken with the 50 cm diameter, 250μ mesh net. Horizontal tows at an average depth of 25 cm were made across two stations within each of the four sections twice monthly between March 1970 and March 1971.

Quantitative estimates of the various plankton organisms were achieved through the use of vertical tows using a 64μ net, with a mouth area of 576 cm^2. These vertical collections were begun in November 1970 and continued until March 1971. Approximately 27 vertical collections were obtained equally distributed over each of the four sections.

Samples were preserved in the field in 5 percent buffered formalin. Laboratory analysis consisted of aliquoting each sample using the Folsom splitter and recording total counts of all organisms in this aliquot. Special attention was given to probably food organisms of the recreational species. The number in the aliquot, calculated total number, percentage abundance of each species relative to the total number of organisms within any one sample, and the average total number of organisms in each sample was recorded for each of the horizontal tows. Similar values were recorded for the vertical tows but, in addition, the total number of each organism per cubic meter was calculated.

2. Crab Nets (70-cm diameter and 5-cm stretch)

Crab net collections were initially taken at all 38 stations. Approximately ten stations, evenly distributed over the entire canal and Manoa-Palolo streams were sampled weekly. Twelve separate variables were recorded for each crab net: station number, tide height, tide direction, depth, salinity, temperature, oxygen, down time, species, width, sex and date. Crab net collections began in October with a few preliminary samples. Systematic collections as described above began in February 1970. Beginning in April 1970, the length of the individuals captured was added to the twelve variables being recorded.

Preliminary analysis of the crab net data at the end of the first six months of the study indicated sufficient consistency in the species and numbers being taken that an adequate sample of the crab population could be obtained from fewer collecting stations. Beginning July 1, 1970, the crab net sampling stations were reduced from 38 to 19 and approximately 6 stations evenly distributed over the study area were sampled every ten days. Collections were terminated in April 1971.

Animals collected were identified, measured, and their sex recorded in the field, then released. Unless otherwise noted, all crab nets were set in the approximate middle of the canal at the noted station.

3. Otter Trawl (3-m opening)

The otter trawl, or "try net" as it is sometimes known, is a particularly useful collecting device in estuarine studies. Properly weighted and slowly towed, it samples the top few centimeters of sediment in addition to sweeping the water area a meter or more above the bottom. Invertebrates dwelling in the surface centimeters of sediment are collected as well as the benthic-dwelling crabs, shrimp and fish. Trawls were conducted in three of the sections of the canal twice each month. Occasionally such large collections were obtained that only one trawl per month was taken in a particular section. Conversely, when no organisms were encountered, additional trawls per month were conducted. Systematic sampling began in February 1970 and ended in March 1971.

The otter trawl was towed across the equivalent of approximately two stations (200 m) in each of the three sections sampled. Rather frequently, the trawl snagged on some large submerged item (chairs, 55-gallon oil drums, shopping carts, etc.) in which case the tow was necessarily terminated.

All animals captured in the trawl were identified in the field, measured (standard length for fish; length and width for crabs), the sex of the Crustacea noted, and then released. Dead fish were retained and preserved for future reference as needed.

4. Gill Nets (100 feet x 5 feet; 2-1/2 inch stretch)

Nylon gill nets were set twice a month in each of the four sections of the Canal. Regular collections began in February 1970 and terminated in April 1971. The nets were set perpendicular to the Canal walls and extended across the midline of the Canal.

The nets remained in place for a minimum of 1 hour to a maximum of 4 hours with a "typical" downtime of approximately 2 hours. Records were kept of the standard length and species of all fish collected and the length, width, sex and species of all crabs. Dead specimens and/or live representatives of the catch were retained for stomach content and pesticide analyses (Shultz, 1971). The remaining live fish and all crabs were measured and released.

III. RESULTS AND DISCUSSION

A. Physical Measurements

Approximately 2,400 measurements of the three physical parameters, salinity, temperature and oxygen have been recorded, 800 for each parameter, from February 1970 through April 1971. The observations were approximately equally distributed between the surface and bottom measurements. A discussion is presented of these values with respect to their horizontal and vertical distribution in the Canal and the effect of season and tide on this distribution. The data are examined from the aspect of effect on the organisms in the Canal. A detailed analysis and discussion of the effect of runoff, tides and wind on the physical parameters in the Canal as well as general circulation patterns is presented in the report by González, 1971.

1. Salinity

a. Horizontal and Vertical Distribution

The general trend of salinity in the Canal is one of considerable horizontal variation in the surface waters and minimal variation in the bottom waters (Fig. 2).

Stations 1-5 show little variation in average surface salinity (Fig. 2; Table 1), and reflect the moderating influence of the ocean. The average salinity at the surface in this section ranged from 20.55 to 25.40 $^{o}/oo$. The average bottom salinities in section I are 11 to 14 $^{o}/oo$ higher than the corresponding surface waters, and range from 31.63 to 34.87 $^{o}/oo$.

Surface values at stations 6-17 are similar, ranging between 16.87 and 28.30 $^{o}/oo$ (Table 1), and reflect the overall daily variations in surface salinities that are observed in the Canal. Surface salinities are slightly lower and more variable in section II than in section I. The rather high variability over this section also reflects the influence of the two small drainage canals which enter the Canal opposite station 11 and 15 (Fig. 1). The comparatively high average surface salinity at station 6 may be the result of the influence of the higher salinity bottom waters in the small basin at that station. The average bottom salinity values at stations 6-17 show slightly less variation than those recorded from stations 105, and generally lie between 33 and 34 $^{o}/oo$ with the exception of the average value of 28.90 $^{o}/oo$ calculated for the bottom salinity at station 17, the entrance to the Manoa-Palolo streams.

Section III, stations 18-30, shows a steadily increasing average surface salinity with distance eastward ranging from 20.37 $^{o}/oo$ at station 18 to 32.80 $^{o}/oo$ at station 30 (Fig. 2; Table 1). The average bottom salinity values in section III are similar to those encountered at stations 6-17. Station 29 yields a lower average salinity due to the presence of a major storm drain near that site.

Average surface salinities in section IV fluctuate widely and ranged from 19.28 to 30.03 $^{o}/oo$. The average bottom salinity in this stream area is slightly less than the average recorded for the Canal proper and ranges from 25.28 to 33.50 $^{o}/oo$ (Fig. 2; Table 1).

b. Seasonal Distribution

The seasonal variation in the average surface and bottom salinity in each section is presented in Table 2. Seasonal variation in the salinity of the surface waters throughout the Canal shows relatively little fluctuation from March 1970 through June 1970. Beginning in July, values reflect the heavy rainfall, with low average salinity figures obtained in the middle of the month. From August through January 1971, a general decrease in surface salinity was recorded. Beginning in February through March 1971, conditions returned to approximately the same values as were observed in the previous year and period.

Bottom salinity values showed much less seasonal change and remained stable from March 1970 to December 1970. Beginning in January 1971, some fluctuation was observed with salinity values decreasing in the bottom waters in all four sections of the Canal. This may be attributed to heavy rainfall in the months of January, February and March. Stations 1-5 and 6-17 exhibited similar seasonal trends in salinity from February 1970 through April 1971 (Table 2). Slightly higher salinity values were present at stations 18-30 which lie east of the stream and receive a minimum amount of influence from the stream as compared to the western section of the canal. In the Manoa-Palolo streams, section IV (Table 2), seasonal variation was evident in the wide range of salinities recorded from October 1970 to January 1971, as compared to the variation observed from March 1970 through September 1970.

In summary, the seasonal variation is most readily apparent in the surface waters which receive the greatest influence from fresh water run-off and the Manoa-Palolo streams. Monthly variations in salinity at the bottom are affected only by the extreme events of seasonal precipitation.

c. Tidal Effects

Mixing generated by the wind and tides is a major factor affecting salinities and total water environment in all four sections of the Canal (Gonzalez, 1971). The horizontal distribution of surface salinity on an incoming tide shows a general trend toward higher salinities with distance eastward (Fig. 3). The variability of the bottom water is greatest from stations 1-5, nearest the ocean entrance on an incoming tide, and shows a progressive decrease in variability with distance eastward. At stations 8-30 the incoming bottom water shows little variation, with the single exception of station 17 (Table 3). Stations 31 through 37 show a progressive decrease in bottom salinity with distance upstream, on an incoming tide.

The effect of the tides on the surface salinity in the Canal is most prominently displayed on an outgoing tide (Fig. 4). There is a considerably wider variation in surface salinity from one station to the next on an outgoing tide as compared with an incoming tide (Fig. 4).

The variation observed in the bottom salinity on an incoming tide at stations 1-7 is no longer present on an outgoing tide. Higher values at stations 5 and 6 reflect the deeper water at those locations. The slight decrease in salinity at station 15 reflects the effluent from the Manoa-Palolo streams which empty at station 17. The low value at station 29 results from the fresh water entering the Canal through the two main storm drains in the shallow upper end of the Canal. The bottom waters of the stream display less horizontal variation in salinity on an outgoing tide.

Salinity values in section III, stations 18 to 30, are primarily influenced by the bottom topography of the Canal. Sediment from the stream has been deposited over the general area from stations 14 to 17 in section II, severely restricting the circulation of the bottom water in section III (see Fig. 5). A deep basin exists in section III at stations 24-26. Surface water flows over the sill and enters the inner section on an incoming tide. It is partially mixed with the low salinity water which enters the Canal from the Manoa-Palolo streams at station 17 as it flows into the inner section. As a result of this partial mixing, the water entering section III is of sufficiently low salinity (and therefore low density) to remain at or near the surface as it flows over the denser inner waters (see Fig. 5A). On an outgoing tide the surface water flows out of section III having undergone very little, if any, mixing with the deeper waters. The deeper water is effectively blocked from flowing seaward by the bottom configuration of the basin and sill (see Fig. 5B). The direct consequences of this bathymetric condition are the high salinities and extremely low oxygen values recorded in the basin.

2. Temperature

a. Horizontal and Vertical Distribution

The horizontal distribution of mean temperatures at each of the 38 stations shows exceptionally little variation ranging from 25.09° to 29.17°C (Table 4). Stations 1 to 11 show slightly more variation in the average temperature as compared to the inner section of the Canal, possibly as a result of the influence of the stream and storm drain effluent in that area and the shallow depth of the water. A general trend is observed toward warmer surface and bottom temperatures with distance eastward from the ocean entrance (Fig. 6).

b. Seasonal Distribution

Of the three main physical parameters measured, temperature shows the most definite seasonal distribution. In all sections, for both surface and bottom observations there is complete consistency in the seasonal high temperatures in July, August and September, and in the low values in November, December and January. This typical seasonal trend is illustrated for section II in Fig. 7.

Beginning with section I, in March 1970 through September 1970, the monthly averages of surface temperature data were consistently slightly higher than average bottom temperatures. In October they were the same and in November through January they were consistently lower than average bottom temperatures. In each case surface values fluctuate slightly more from month to month than corresponding bottom values (Table 4).

There was a general trend beginning in March and extending to July, August and September of steadily increasing surface temperatures. In September the surface temperatures began to drop to reach a low in December. The bottom data follows the same general trend of increase and decrease throughout the year, but with slightly less range.

Section II shows a similar trend throughout the year. Surface temperatures were consistently high relative to the bottom temperatures from February through September, 1970. In

October surface and bottom temperatures were similar. The November through February surface temperatures were lower than bottom values. The March and April 1971 surface and bottom temperatures for section II were identical.

Surface temperatures in section III were not appreciably different from those encountered in sections I and II. There was however a decided difference in bottom temperature as compared with surface temperature. The seasonal range of variation in the bottom waters is approximately 3° as compared with approximately 8° in the surface waters (Table 5). The same trend of warmer surface temperatures in the spring and summer, as shown before, and a low value in January is apparent in both the surface and bottom records.

Temperature data taken for section IV show perhaps the greatest fluctuations over the year. Despite the rather wide range of values noted in this region, the trend we have noted before of consistently high surface-water temperatures through the summer and cooler temperatures in January is apparent. From February to June, 1970, the surface water was consistently warmer than the bottom water. Beginning in July through October the values of the surface and bottom water were the same. In November and December the temperature of the bottom water was consistently warmer than the surface water. (This condition is possible because of the high salinity of the bottom water.) The January and February surface and bottom values were similar. The March value indicates a warmer surface temperature and the April value, a cooler value. These rather wide variations and lack of particular trend in the last four months of data reflect the generally wide range of variation of all environmental conditions exhibited by the waters of the Manoa-Palolo streams.

c. Tidal Effects

Differences between surface and bottom temperatures throughout the Canal and Stream are much less pronounced than the differences observed in salinity--until we include the tide direction in our analysis (Fig. 8). Temperatures from stations 1-16 and 31-38 appeared to be randomly distributed with respect to higher or lower temperatures at the surface or bottom at any one station. However, on further examination of Figure 8, which plots average temperatures at the surface on an incoming tide and the corresponding bottom data collected at the same time, it is found that at 95 percent of the stations the surface temperature is 1°C or more higher than the bottom temperature. A similar comparison of the surface and bottom data taken on an outgoing tide yields a significantly different result; only 44 percent of the stations have surface temperatures higher than bottom temperatures (Table 6).

3. Oxygen

a. Horizontal and Vertical Distribution

In very general terms, irrespective of depth or tide, stations 1-13 show a fairly uniform distribution of dissolved oxygen with average values ranging from approximately 5.5 to 7.5 ppm. Higher average values at stations 14-18 and 30 reflect the shallow depth, wind-driven mixing of saturated surface waters, and high content of dissolved oxygen waters from the Manoa-Palolo streams and the drainage canals. By contrast, stations 20-28 are primarily influenced by the low, sometimes anoxic, waters in the basin near those stations. Stations 31-38 are high in dissolved oxygen, for reasons similar to those mentioned for stations 14-18 and 30.

Examination of the dissolved oxygen data for the surface and bottom yields more definitive data as to horizontal and vertical distribution (Table 7; Fig. 9). Surface values of dissolved oxygen are higher than the corresponding bottom values at all stations. This difference between the surface and bottom values is smallest, amounting to approximately 2-4 ppm, at stations 1-18, and largest, 5-8 ppm, at stations 19-30. This is a direct result of the minimum circulation in the inner as compared to the outer sections of the Canal due to the bottom topography, i.e., the sill-basin configuration discussed previously (see Fig. 5). Attention should be called to the extremely low values (less than 3 ppm) of dissolved oxygen recorded at the bottom for stations 20-28 (Table 7). Stream stations 31-38, exhibited approximately 3-4 ppm difference in dissolved oxygen favoring the surface waters.

b. Seasonal Distribution

Monthly averages of surface and bottom oxygen (Table 8) yield no conclusive results as to seasonal trends in the distribution of dissolved oxygen. There may be a slight increase in March, April and May and minimum values in the winter months of October, November and December, but the evidence is inconclusive.

c. Tidal Effects

Tide direction has a minimal influence on the distribution of dissolved oxygen horizontally and vertically (Table 9). There was no particular correlation between surface or bottom dissolved oxygen values taken on an incoming or an outgoing tide. The average values recorded for surface oxygen on an outgoing tide show slightly more variation from station to station than those taken on an incoming tide, particularly at stations 9-21 and 31-38. A very slight increase in surface oxygen may be present on an outgoing tide as compared with an incoming tide. A slightly narrower distribution of oxygen is observed from station to station in the bottom samples on an outgoing tide, particularly at stations 20-28.

B. Biological Data

1. Zooplankton

The major purpose of the zooplankton samples was to provide information on these organisms which may be a part of the food chain of the crustacean and fish species of recreational value. A total of 28 organisms was recorded from the zooplankton samples (Fig. 10. Of these, twenty organisms were generally numerous and widespread, and were considered of primary importance in the food chain. The zooplankton were approximately evenly divided between numbers of species of holoplankters and meroplankters. In number of individuals and volume, the holoplankters frequently occurred in a 2:1 ratio with the meroplankters, due primarily to the abundance of copepods. Perhaps the most remarkable observation to emanate from this project is not the difference in kinds of organisms that exist from one section to another, but rather the great similarities in their occurrence throughout the Canal and even the Manoa-Palolo streams. With very few exceptions, all zooplankton organisms recorded in this study were present throughout the Çanal and Stream.

The horizontal distribution, frequency of occurrence, total number, seasonal distribution, and distribution relative to certain physical parameters are discussed for each of the zooplankton organisms.

a. Amphipods

Amphipods were taken in all sections of the Canal and the Manoa-Palolo streams (Fig. 10), and were recorded in 12.6 percent of all the zooplankton samples (Table 10). Their total numbers ranged from approximately 10 to 320 individuals (Fig. 11; Table 11) which represented less than 2.5 percent of the total organisms of each collection (Fig. 12). The average total number in each section ranged from approximately 20 to 120, with the maximum concentration occurring in section III (Table 11). Although they were most abundant in section III, they occurred in a greater percentage of the tows (18.8 percent) in section II (Table 10). Amphipods are nocturnal animals and remain at or near the bottom during the day. For this reason they would perhaps be more frequently captured in the tows taken over the shallow waters such as encountered in section II as compared with section III. Amphipods were collected with about equal frequency in nets of all three mesh sizes (Table 12) and were present in approximately equal numbers in the collections made with the 64μ nets and 250μ nets. They were slightly less numerous in the 333μ tows.

Amphipods were present in 9 of the 13 months of collections and showed the greatest frequency of occurrence in June 1970, and the lowest in December and February. No amphipods were found in the collections taken in March, April, May and October (Table 13). The geometric mean of their average total number ranged from a high of about 90 individuals per tow in September 1970 to a low of less than 10 in March 1971 (Table 14). For such widely varying numbers, the geometric mean yields a more representative or typical value than the arithmetic mean.

With one exception, amphipods were collected on both incoming and outgoing tides in all sections of the study area (Table 15). They were not found in the five tows taken on an outgoing tide in section IV. The presence of amphipods in roughly the same concentrations in all four sections and in 9 of the 13 months of study would imply no particular limit on their horizontal or seasonal distribution due to variances in salinity, temperature, and/or oxygen in the surface waters.

b. Ascidian Larvae

Ascidian larvae were collected from stations 1 through 22 in decreasing frequency with distance eastward away from the ocean entrance (Fig. 10). They were not present east of station 22 nor were they present in the Manoa-Palolo streams. They occurred in 21.6 percent of the zooplankton collections and their total numbers ranged from approximately 20 to 650 (Fig. 11; Table 10). In 19 of the 24 collections their numbers represented less than 2 percent of the total number of organisms in each collections. In one sample they formed 10 percent of the total number of organisms (Fig. 11). Ascidian larvae showed a significant decrease in frequency of occurrence from section I to section III (Table 10). However, their average total number was greatest in section III (Table 11). They were collected most frequently in nets of 250μ and 333μ mesh size (Table 12) but were taken in approximately the same concentration in all the mesh sizes.

Ascidian larvae occurred most frequently in May, June and October, 1970. They were not recorded in the months of March, April and November, 1970, and February 1971 (Table 13). There was little monthly difference in their total numbers, however the highest average concentration was recorded in June 1970.

Ascidian larvae were collected on both incoming and outgoing tides except for section III, where they were taken in only three tows performed on an outgoing tide (Table 15). Perhaps because of the decreased mixing influence of tide with distance from the ocean entrance, ascidian larvae tend to a more clumped distribution in the inner section resulting in fewer occurrences but higher concentrations where they are present.

Their absence with distance eastward of station 22 definitely implies some factor limiting their horizontal distribution. Salinity variations have been shown to be minimal (Table 1), and temperature values in the surface waters are not significantly different eastward of station 22 (Table 4). Surface oxygen at station 22 shows a sharp gradient to lower values and thus affords the most plausible explanation for the lack of occurrence of ascidian larvae east of that station. Their absence from the Manoa-Palolo streams is apparently not due to adverse conditions of salinity, temperature, or dissolved oxygen, as these parameters in the stream are not significantly different from those in sections I and II.

c. Chaetognaths

Chaetognaths were present in all sections of the Canal and stream (Fig. 10) and they occurred in 71.3 percent of the zooplankton tows (Table 10). Their total number ranged from approximately 40 to 25,000 (Fig. 11; Table 11). On the average they formed 10 percent or less of the total number of organisms in any one tow, however in five collections their numbers accounted for from 12 to 15 percent, and in three collections they formed 21 to 33 percent of the total collection (Fig. 12). They occurred in the greatest percentage of tows taken in section III (Table 10) which corresponded with the highest total number of individuals recorded. Chaetognaths were present in tows with all three mesh sizes, the 250μ and 333μ yielding the highest frequency of occurrence (Table 12).

They occurred in each of the 13 months of sampling with only modest variation in the average total numbers. A minimum number were taken in August and a maximum in December, 1970 (Table 13). There was a definite seasonal change in the frequency of occurrence in the tows. They were present in almost every tow from March through October, 1970. Beginning in November 1970 through February 1971 they dropped steadily and significantly in frequency of occurrence to about one-third their previous level. The last zooplankton collection in March 1971 indicated a twofold increase in occurrence over the previous month and perhaps the beginning of a return to the values observed for those months in the preceding year.

Tide direction appears to have had no influence on the occurrence of chaetognaths in any of the four sections of the study (Table 15). Their relatively constant numbers and wide distribution would indicate that the values of salinity and oxygen recorded for the study area are not limiting their distribution. Their frequency of occurrence apparently decreased in the months of highest average temperatures.

d. Cirripedes

Cirripedes were present in all four sections of the Canal and Stream and occurred in 84 percent of the plankton tows (Table 10; Fig. 10). Their total numbers ranged from 40 to 63,000 (Fig. 11). On the average, cirripedes formed 20 percent or less of the total number of organisms in any one tow. However, in 25 cases they formed considerably more than 20 percent of the total number of organisms and in three cases they formed between 85 and 90 percent of the entire sample (Fig. 12). The average total number of cirripedes in each of the four sections ranged from approximately 2,000 to 6,300 with the maximum number occurring again in section III (Table 11).

Cirripedes were present in collections taken with the 64μ, 250μ, and 333μ nets (Table 12). There was a general increase in the percent frequency of occurrence with increase in mesh size (Table 12). The total number of cirripedes collected with the 64μ and 333μ nets ranged from 60 to approximately 800. In the case of the 250μ net, the total number ranged from 125 to 80,000. One explanation for the considerable difference in total numbers acquired in the 250μ net as compared with the 333μ and 64μ mesh nets is the filtering efficiency of the various mesh sizes and the size of the organism. The 333μ net undoubtedly filtered proportionally more water per tow because of its relatively large mesh size. It would be likely therefore to frequently capture cirripedes; however, because of their small size they are not readily retained by that large a mesh and undoubtedly many more are lost through the net. The 64μ net was impeded in proper sampling due to clogging and therefore filtered proportionally less water and caught fewer cirripedes.

Examination of the frequency with which cirripedes occurred in the various zooplankton tows taken over the year indicated a 100 percent occurrence in April through July 1970. The remainder of the year had months of high values intermixed with months of lower values, but they always occurred in 55 percent or more of the tows (Table 13).

The actual numbers of individuals recorded for the various months yields an entirely different seasonal pattern. The geometric mean of the total number in each sample ranges from a low of approximately 90 in April 1970 to a high of 17,800 and 5,600 in August and September, respectively, (Table 14). In fact, this numeric high correlates with months of the lowest percentages of occurrence.

Perhaps the high total counts in August and September reflect a period of increased clumping or spawning activity prior to more general dispersal as shown in the remainder of the year.

Cirripedes, as was true of chaetognaths, do not appear to be influenced by tide direction in their horizontal distribution (Table 15).

Cirripedes are widely distributed horizontally throughout the Canal, and apparently are not limited by the salinity, temperature, and oxygen values recorded in the Canal. They showed a positive correlation between the months of maximum number of individuals collected and months of maximum monthly temperatures (Tables 5, 14).

e. Cladocerans

Cladocerans were present in only two of the 111 tows of this study and occurred at stations 21-22 and 28-29 (Fig. 10). They were present in very small numbers (six and seven) in these two tows taken with the 250μ mesh net. They were not collected with either the 64μ or the 333μ net. This is an indication of their scarcity in the canal, rather than an indication of the ease of collection with any one mesh size. Cladocerans are known to produce "resting eggs" which are very resistant to adverse environmental conditions (Wickstead, 1965). Hatching occurs when conditions become optimum and the animals quickly become fully developed and capable of producing young of their own. The sporadic occurrence of cladocerans in the zooplankton may be attributed to this reproductive sequence. Their infrequent occurrence and minimal numbers preclude further conjecture as to the factors limiting their distribution in the Canal.

f. Copepod Nauplii

Copepod nauplii occurred in 45.1 percent of all tows taken and were present in all four sections of the Canal and Stream (Fig. 10, Table 10). The average total number yielded values ranging from 2,500 to 1,600 (Table 11). The greatest concentration was recorded from section I (Table 10).

Copepod nauplii occurred in all collections made with the 64μ net and nearly all collections made with the 250μ and 333μ nets (Table 12). In general they were extremely abundant in all areas sampled. The number of copepod nauplii varies considerably with the mesh size used in the collection. With the 64μ mesh net, the total number ranged from approximately 100 to 142,000; with the 250μ net, the total number ranged from 10 to 5,000; and with the 333μ net, from 4 to 800 (Table 12). It is safe to conclude that copepod nauplii are more readily captured in the smaller mesh net and that measures of their abundance based on collection using 333μ or even 250μ net introduce serious error.

On examining the number of copepod nauplii relative to the numbers of all zooplankton species (Fig. 12), one observes that copepod nauplii are second only to Pseudodiaptomus adults in regard to their total numbers. They were exceedingly abundant in the 50 collections where they occurred (Fig. 12), and in 9 cases they formed approximately 85 percent or more of the total organisms in the sample. In 21 cases they formed approximately 12 percent or less of the total number of organisms in any one sample. The remaining 20 samples were rather evenly divided over the range from 20-80 percent (Fig. 12).

Copepod nauplii show a seasonal distribution. They were exceedingly abundant from November 1970 to March 1971, but they were absent from June 1970 to October 1970. They occurred in smaller numbers in April and May, 1970 (Table 13).

Copepod nauplii were distributed in all four sections of the Canal on an incoming tide (Table 15), but were not present from stations 22 to 30 on an outgoing tide. That area is one of rapidly decreasing surface oxygen which may negatively influence their distribution. Temperature and salinity are not considered limiting in that section.

g. Copepod Adults

An estimated 95 percent of the copepod adults enumerated in this category were Acartia. The remaining 5 percent included Pseudodiaptomus.

Copepod adults were present in all four sections of the Canal and Stream and occurred in 94.6 percent of all samples taken (Fig. 10; Table 10). The numbers of adults in the 104 collections in which they occurred ranged widely from approximately 10 to 100,000 individuals with the greatest percentage of the samples containing more than 3,000 (Fig. 11); eleven samples contained 90-99 percent (Fig. 12).

The average total number of adults showed a progressive increase from section I to section IV, ranging from about 9,700 to 17,700 (Table 11); the greatest total numbers were in the Manoa-Palolo streams. They were present in every collection made with the 64μ net and with nearly every collection made with the 250μ and 333μ mesh nets (Table 12); the total number was greatest in those collections made with the 250μ net, but there was nearly comparable success with the 64μ and 333μ mesh collections. The 74μ and 333μ nets were not generally used in the Stream and thus the total number captured with those nets may be in error due to the greater concentration of adults in the Stream.

There was no particular seasonal trend in frequency of occurrence of the adults in the zooplankton tows. They were persistently one of the most frequently collected organisms.

The monthly distribution of total numbers of adults showed a slight decrease in May and June, 1970. The greatest concentrations occurred in September 1970 and March 1971 when their numbers rose to a geometric mean of approximately 12,500.

Tide direction did not influence the frequency of their occurrence (Table 15).

There was no correlation of their distribution relative to temperature or dissolved oxygen in the Canal. However, the December and February months of high concentration of individuals does correlate with periods of exceptionally low surface salinities (Table 2). This observation combined with the large concentration noted in the stream leads to speculation that the copepod species found in the Ala Wai, primarily species of _Acartia_ and _Pseudodiaptomus_, may "prefer" a low-salinity environment.

h. Crab Megalops

Crab megalops were taken only in sections II and III (Fig. 10), and were present in less than 5 percent of the total number of samples (Table 10). In number they were represented by an average of from 10 to 15 individuals (Table 11), the greatest number occurring in section III, and in every case where they occurred they formed less than 1 percent of the total sample (Fig. 11). They were collected only in the 250μ net where they were taken in 7.3 percent of the tows (Table 12). In four of the five collections containing them, the average total number was 22. The fifth collection contained about five. They were collected on both incoming and outgoing tides (Table 15); however, their generally limited occurrence precludes further discussion of the influence of the physical or seasonal factors on the distribution of this plankter.

The megalops stage of development is the intermediate stage between the truly planktonic zoea and the benthic-dwelling adult. As such, the megalops may be more concentrated near the bottom, which would explain their limited numbers at the surface as compared with the numbers of crab zoeae.

i. Crab Zoeae

Crab zoeae were present and exceedingly abundant in all sections of the Canal and Stream (Fig. 10). They were taken in 84 of the 111 tows for a 75.6 percent overall frequency of occurrence (Table 10; Fig. 10). In total number, they ranged from a low value of approximately 10 to a high of 10,000, with the greatest percentage of samples yielding counts in the vicinity of 100 to 1,000 (Fig. 11).

The frequency with which they were collected increased slightly but steadily from 73.1 percent in section 1 to 84.8 percent in section III, then dropped to a low of 60 percent in section IV. The average total number ranged from a high of 1,180 in section III to a low of approximately 450 in section IV (Table 11).

Collections made with the various mesh sizes gave slightly different results as to the frequency of capture (Table 12). Crab zoeae were collected in 14.3 percent of the 64μ samples, 95.6 percent of the 250μ samples, and 100 percent of the 333μ samples. It was concluded that they were more readily captured in the 250μ and 333μ nets; it is probable that the larger mesh results in a significant loss of the zoeae sample.

The zoeae showed a definite seasonal trend in frequency of occurrence. They were present in all samples taken from March through September, 1970. Their frequency of occurrence then declined steadily to a low of 46.7 percent in January 1971, after which it began a steady upward rise (Table 13). The total numbers of individuals collected throughout the year (Table 14) showed little or no such seasonal trend.

Zoeae were taken about equally on both incoming and outgoing tides (Table 15), but there was a possible slight increase in occurrence on an incoming tide. Their occurrence or concentration was not correlated with the distribution of salinity, temperature, or dissolved oxygen.

j. Echinoderm Larvae

Echinoderm larvae showed a rather limited distribution in the Canal, being found only in sections I and III and then occurring in only 4.5 percent of the zooplankton samples. Their total numbers in these samples ranged from approximately 30 to 120. The larvae occurred in 12.1 percent of the tows taken in section III (Table 10), and were present in the greatest concentration in that section (Table 11). The average total number ranged from 24 in section I to 106 in section III (Table 11; Fig. 10). Larvae were collected in 14.3 percent of the tows with the 64μ net as compared with 1.5 percent of the tows with the 250μ net. They were not collected with the 333μ net (Table 12). The total numbers recorded were greatest for the 64μ net samples. It seems evident that they are not adequately sampled with the larger mesh nets. The larvae were collected on both incoming and outgoing tides (Table 15), but were present too infrequently to allow for conclusions to be drawn concerning their seasonal distribution or the effects of temperature, salinity, and oxygen on their distribution.

k. Fish Eggs

Fish eggs, for the most part tentatively identified as belonging to the nehu, were collected in 55.9 percent of all the tows and were taken in all sections of the Canal and Stream (Table 10; Fig. 10). Their total numbers ranged from less than 10 to more than 8,000 (Fig. 11), with the greatest percentage of the tows yielding values between 100 and 1,000. They comprised 13 percent of the total sample in all but two cases where they formed between 19 and 21 percent (Fig. 12). They occurred most frequently and in greatest numbers in section III where they were taken in 72.7 percent of the tows (Tables 10, 11).

Fish eggs were taken in all three mesh sizes but showed a steady increase in frequency of capture with increase in mesh size (Table 12). The 64μ net was not quite so effective in collecting them as the 250μ and 333μ nets, which yielded approximately equal numbers.

Their monthly distribution shows a slightly greater frequency of occurrence in May and November, 1970 and a rather distinct decrease in January and February, 1971. No comparable pattern was displayed for the distribution of the toal numbers, which generally yielded similar values for all months with a very slight increase in average total numbers recorded in August 1970 (Table 14).

Fish eggs were approximately equally distributed over the Canal and Stream on an incoming or outgoing tide (Table 15). Their distribution does not show any particular correlation with the physical parameters of salinity, temperature, and dissolved oxygen.

l. Fish Larvae

Positive identification of the various species of larval fish requires extensive research and was considered beyond the scope of this project. Our primary concern was in defining the various elements of the food chain of recreational organisms. Hence, larval fish are treated as a single class of organisms.

Fish larvae were taken in 38.7 percent of the zooplankton tows and were recorded from all sections of the Canal and Stream (Table 10; Fig. 10). The total numbers ranged from a few to 2,500 individuals collected in each tow (Fig. 11). In essentially all cases, they formed less than 10 percent of the total sample (Fig. 12).

The larvae occurred in nearly identical frequency in all sections of the Canal and Stream. The average total number in each section showed a progressive increase in numbers collected from section I to section III. Section IV yielded average total numbers that are similar to those of section II (Table 11).

They were collected with each of the three mesh sizes. The greatest frequency of catch was with the 250μ net which also yielded the most individuals (Table 12).

Larvae occurred most frequently in the tows of July, October, and November, 1970 (Table 13). The number of tows containing them each month was not correlated with the number of individuals recorded for any given month (Table 14). There was an apparent significant increase in their numbers from June 1970 to November 1970. A marked decrease in abundance was then observed in December continuing to March 1971. It may be noted that March 1970 had a similar low value (Table 13); one sample in November contained 10 percent (Fig. 12).

There did not appear to be any correlation between their occurrence or numbers and tide direction (Table 15), salinity, temperature, or oxygen values.

m. Isopods

Isopods were present in all four sections of the Canal but were extremely limited in occurrence (Fig. 10). They occurred in 27.3 percent of the tows taken in section III (Table 10). The average total number ranged from 16 to 64, with the higher values occurring in sections II through IV (Table 11). In six out of the seven occurrences, they formed 2 percent or less of the sample. In one case they formed approximately 4 percent of the total sample (Fig. 12). They were taken in a total of seven samples, six with the 250μ net and one with the 333μ net (Table 12). Their total numbers ranged from approximately 20 to 80 (Fig. 10).

Isopods occurred very infrequently but are apparently present throughout the year and in roughly the same concentrations.

Isopods were not taken on an outgoing tide. This may reflect an actual case of change in vertical distribution with tide direction. It is possible that they are capable of descending to, at, or near the bottom on an outgoing tide, thus inhibiting their seaward flow. This would explain their lack of occurrence in the surface collections as well as their slightly higher numbers in the inner sections of the Canal.

Their slight increase in numbers with distance from the ocean may reflect a preference for waters of slightly higher salinities (Table 11).

n. Lucifer Adults

Lucifer adults were present in all sections of the Canal and Stream (Fig. 10) and occurred in 18.9 percent of all samples taken (Table 10). They occurred with about equal frequency in sections I, II, and IV but were slightly more frequent in section III (Table 10). Their average total numbers in each section ranged from 153 to 216 (Table 11). The range of the total number is from approximately 40 to 1,020 (Fig. 11). In 19 of the 21 collections, they formed less than 2 percent of the total collection. In two samples they formed approximately 3 percent of the total sample (Fig. 12). They were collected in a total of 21 samples, 20 of which were taken with the 250μ net and one with the 333μ net (Table 12).

Variation in seasonal distribution is questionable, but there may have been a slight increase in average numbers of adults in February 1971 (Table 13). They occurred in the greatest percentage of the tows taken in October 1970 and March 1971 (Table 14) and were absent from the tows taken in May, June, and September, 1970.

Adults were taken from all sections on an incoming tide (Table 15). They were not taken east of station 21 nor in the stream on an outgoing tide. Surface salinity on an outgoing tide is significantly more variable and lower than that recorded at the same station on an incoming tide (Figs. 3, 6). This is particularly true of the area east of station 21 and in the Manoa-Palolo streams. It is possible that the adults are able to avoid the surface waters at this time. Temperature and oxygen values do not show such a marked change with tide direction and show no particular correlation with their distribution.

o. Lucifer Protozoeae

Lucifer protozoea were present in all four sections of the Canal and Stream (Fig. 10). They were taken in 41.4 percent of the tows and were collected with slightly less frequency in section IV (Table 10). The average of their total numbers in each section ranged from about 100 to 800, with the low value occurring in section IV, the high in section III (Table 11). They were taken most frequently with the 250μ and 333μ net (Table 12). In total numbers, they ranged from a few individuals to approximately 8,000. In 43 of the samples the protozoea formed 10 percent or less of the total number of organisms; in three samples they formed from 10 to 20 percent of the total; and on three occasions they formed from 60 to 65 percent of the total sample (Fig. 12). They were collected in a total of 46 samples and in all three mesh sizes (Fig. 12).

The seasonal distribution appears to show a greater total number of the protozoeae in August 1970 and February and March, 1971, with a low in October and November (Table 14). In terms of percent frequency of occurrence a different distribution is indicated. They occurred in the greatest percentage of samples in May, June, and October (Table 13). There is no apparent correlation of this distribution with seasonal changes in temperature, salinity, or oxygen. They were collected from all four sections on both incoming and outgoing tides (Table 15).

p. Medusae

Medusae were present in all four sections of the Canal and Stream (Fig. 10), and occurred in 64, or 58.6 percent, of all the samples taken (Table 10). Their average total number in each section ranged from approximately 150 to 3,700 with the highest number occurring in section III and the lowest in section I (Table 11). For the most part, they formed less than 10 percent of the samples in which they were present. In 11 of the 64 collections, they comprised from 11 to 65 percent of the total sample (Fig. 11). They were present in nets of all three mesh sizes with steadily increasing mesh size (Table 12). The total number collected with each of the different mesh sizes indicated that the 250µ net collected higher total numbers of medusae than did the other nets. Based on total collection irrespective of net size, the log of the total numbers ranged from 1.0 to 4.8 (Fig. 11).

There appears to be a true low number of medusae occurring in November as compared with the rest of the year (Table 14). They were present in all sections on both incoming and outgoing tides (Table 15). No correlation of their distribution with salinity, temperature, or oxygen was apparent.

q. Molluscs

Molluscs were taken in a total of 57 collections or 50.4 percent of the samples (Table 10). They were present in all four sections of the Canal and Stream with a slightly greater frequency of occurrence in section I (Table 10; Fig. 10). The average total number of molluscs present in each of the four sections ranged from a high of 283 and 257 in sections I and III, respectively, to a low of 82 and 72 in section II and IV (Table 11). The log of the total numbers irrespective of mesh net size indicated a range in abundance of .6 to 3.4 (Fig. 11). In all 57 collections, molluscs provided less than 15 percent of the total number of organisms in each sample (Fig. 12). They were present in nets of all three mesh sizes, but occurred most frequently in the 250µ samples (Table 12).

A possible seasonal trend was observed in their distribution (Table 13). There appeared to be a significant decrease in numbers in June and again in October and November, with maximum values appearing in July, September, and December.

The seasonal pattern in terms of percent frequency of occurrence in the sample tows indicated only a 20 percent occurrence in the April 1970 tows as compared with 75 percent of the September tows. The high frequency of occurrence in the September tows correlates with the relatively high numbers of individuals recorded for that month (Tables 13, 14).

The distribution of temperature and oxygen shows no correlation with their distribution (Figs. 7, 9). Average salinities in all four sections are extremely low in the surface waters in November, which correlates well with their decrease (Tables 2, 10). However, the salinity is extremely low in December also and apparently they were abundant at that time. They were collected from all stations on an incoming tide but were not present east of station 21 on an outgoing tide (Table 15).

r. Mysids

Mysids were not common in the Canal and occurred in only two collections, at stations 3 and 4 (Fig. 10). In percent frequency of occurrence, they were taken in 1.8 percent of the samples (Table 10). Their average number was about 40 (Table 11). They were collected in one tow each with the 250μ and 333μ nets (Table 12). The log of the total number (1.6) collected with each net was identical for both samples (Fig. 11). In both cases they formed less than 2 percent of the total sample (Fig. 12). They occurred in insufficient numbers to evaluate their seasonal or tidal distribution. It is likely that the physical parameters, particularly salinity and oxygen, are limiting their distribution in the Canal.

s. Nematodes

Nematodes were recorded in one sample at station 33 (Table 10, Fig. 10). The log of their total number was 1.3 (Fig. 11). They were taken only in the 250μ net where they were found in only 1.5 percent of the tows. As they were present in only one sample further discussion on their distribution is not practical.

t. <u>Oikopleura</u>

<u>Oikopleura</u>, the tunicate, was present in all sections of the Canal and Stream but of very limited occurrence within these sections, being present at only eight stations for 7.2 percent of the total number of samples (Table 10; Fig. 10). The

average of the total numbers occurring in each section ranged from a minimum of 40 in section II to a maximum of 200 in section I (Table 11). Disregarding mesh size, the log of the total number of Oikopleura ranged from 1.0 to 2.9 (Fig. 11). It was captured in both the 250μ and 333μ nets for a total of eight collections in all (Table 12). Its percent frequency of occurrence in the 250μ net was slightly lower than for the 333μ net (Table 12). In six of the tows, it provided less than 1 percent of the total number of organisms. In the other two tows, it provided 30-36 percent of the tow (Fig. 12).

Oikopleura was taken rather sporadically throughout the year and does not display a definite seasonal distribution (Tables 13, 14). It was collected on both incoming and outgoing tides (Table 15). There was no specific correlation of its monthly distribution with averages of salinity, temperature, or oxygen (Tables 2, 5, 8).

u. Ostracods

Ostracods occurred in 12.6 percent of the tows and were present in all four sections of the Canal and Stream (Table 10, Fig. 10). The average total number in each section showed a high of 61 in section III and a low of 16 in section I (Table 11). The log of their total number ranged from about .8 to 2.2 (Fig. 11). A total of 14 samples containing ostracods were collected. Nine were taken with the 64μ net and five with the 250μ net (Table 12). They were present in 32.2 percent of the 64μ tows as compared with 7.3 percent of the 250μ tows (Fig. 12). It would appear that the 64μ net was slightly more effective than the 250μ net. Of the 14 collections containing them, ostracods always formed less than 2 percent of the total samples (Fig. 12). Factors influencing their distribution, such as season, temperature, salinity, and oxygen, are not conclusive from the data gathered (Tables 13, 14). They were collected on both incoming and outgoing tides (Table 15).

v. Polychaetes

Polychaetes were among the most numerous of all the zooplankton organisms, were consistently in 60 to 65 percent of the tows, and were exceedingly abundant in all four sections of the Canal (Fig. 10). The average total number in each section ranged from just under 300 in section II to almost 2,000 in section III (Table 11). The log of the total number ranged from .6 to 4.4 (Fig. 11). In 59 of the 71 tows in which they were recorded, they formed less than 10 percent of the total sample. In the 12 remaining tows they formed from 12 to 43 percent of the total number of organisms in any one tow (Fig. 12).

Polychaetes were captured in each of the three mesh sizes. They were most frequently caught in the 64μ mesh, occurring in 92.7 percent of the tows made with that net. They occurred next most frequently in the 250μ net (57 percent) and least in the 333μ (40.0 percent) (Table 12). The log of their total number collected in each of the different nets ranged from 1.0 to 4.4 in the 64μ net, .6 to 3.3 in the 250μ net, and .1 to 2.9 in the 333μ net. It was readily apparent that the 64μ net was superior to the larger mesh sizes in their capture (Table 12).

Their seasonal distribution shows a definite trend to higher numbers from October 1970 to March 1971, and a decrease in abundance in the remainder of the year (Table 13). This corresponds to a slight decrease in average surface salinity and temperature, and an increase in surface oxygen (Tables 2, 5, 8). They were readily collected in approximately the same percentages on both incoming and outgoing tides from all four sections (Table 15).

w. *Pseudodiaptomus* Adults

Pseudodiaptomus adults were present in all four sections of the Canal and Stream (Fig. 10). They were recorded in 27.0 percent of the total collections and were present in a progressively decreasing percentage of the tows with distance from the Canal entrance (Table 10). The average total number ranged from less than 20 in section II to almost 30,000 in section I (Table 11). The log of their total numbers ranged from .1 to 5.4 (Fig. 11). In seven of the 30 collections, they provided less than 5 percent of the total sample. However, in four cases it accounted for between 35 and 75 percent of the total sample (Fig. 12). They occurred in 7 percent of the tows taken with the 64μ net and 33 percent of those taken with the 250μ and 333μ nets (Table 12). The log of the total number of adults collected with the 64μ net ranged from 4.1 to 5.4; with the 250μ net, .6 to 4.4; and with the 333μ net, .1 to 2.2. It was apparent that they were taken more readily in the 64μ net.

The seasonal distribution is inconclusive; it would appear that December and March may be months of greater abundance, but that is open to question. Again, there is no definite correlation of the physical parameters with the abundances recorded. Adults were present on both incoming and outgoing tides (Table 15).

x. Shrimp

The term shrimp applies to the mixture of caridean and penaeid organisms which were abundant in all four sections of the Canal (Table 10, Fig. 10). A total of 77.5 percent of all plankton tows contained species of shrimp. The average total numbers in each of these tows ranged from a low value of 94 in section II to a high of 768 in section IV (Table 11). The log of the total number ranged from .6 to 3.8 (Fig. 11). They formed less than 10 percent of the total sample in 84 of the 88 samples, but on one occasion they formed 75 percent of the total sample (Fig. 12). They were taken in all three mesh sizes. They were collected in every tow made with the 250μ and 333μ net but were present in only 10.7 percent of the tows taken with the 64μ net (Table 12). It is probable that the finer mesh was less efficient in collecting them due to clogging and the resultant decrease in volume of water filtered.

The distribution of shrimp throughout the season indicated a relatively constant number of organisms and does not present any particular pattern of seasonality (Table 13). As such there was also no apparent connection with the observed seasonal distribution of temperature, salinity, and oxygen (Tables 2, 5, 8). In respect to tide, they were taken with equal frequency on both incoming and outgoing tides in all four sections (Table 15).

y. Stomatopods

Stomatopods were present in only 5.4 percent of the tows and only in sections I and III (Table 10; Fig. 10). They were more numerous in the inner section than at the entrance (Table 11). The average total number in each of the two sections ranged from 42 to 160 (Table 11). They were taken in a total of six collections in the 250μ mesh net. The log of the total number collected with this net ranged from 1.4 to 2.4 (Fig. 11). In all cases they formed less than one percent of the total sample (Fig. 12).

z. Dipterans

Dipterans, other insect larvae, and mites were present so infrequently and in such few numbers that further discussion of their distribution is not feasible.

Of the 28 organisms recorded in the plankton tows, only 5 occurred in sufficient numbers and with adequate frequency to be considered of significant importance in the food chain of the recreational species of fish. First in numbers and frequency of occurrence in all sections including the Stream were the various species of copepods and their associated nauplii. There were some differences in the relative importance of the other five plankters, depending on the section of the Canal. In section I, crab zoeae and cirripedes were second in importance to copepods with the remaining species generally showing sporadic occurrence. Section

II had somewhat similar characteristics, but crab zoeae showed a marked decrease in total number, with a decided increase in numbers of cirripedes. The frequency with which these two species occurred remained high and relatively stable and did not correlate with the total numbers. Cirripedes, medusae, polychaetes, and crab zoeae, in that order, were abundant in section III. Section IV was overwhelmingly dominated by copepods but did yield nearly a third as many cirripedes.

Some species of holoplankters, mostly chaetognaths and Oikopleura, frequently occurred in profusion, but they are apparently little consumed by the recreational species of fish or crabs. Their importance in the general food chain of the recreational species arises from their joint grazing on other zooplankters.

2. Benthos (Crustacea)

Five species of macrocrustacea have been recorded from crab nets, gill nets, and otter trawls: Podophthalmus vigil, Thalamita crenata, Scylla serrata, Portunus sanguinolentus, and Squilla oratoria. Of these five species only the first two can be considered sufficiently abundant to be of recreational importance.

Podophthalmus vigil, the Hawaiian swimming crab, was very abundant but distinctly restricted in its horizontal distribution. It occurred in significantly greater numbers between stations 8 and 13 (Fig. 13), and was never taken east of station 20.

Thalamita crenata, the blue claw crab, demonstrated the widest horizontal distribution, being present throughout the Canal and Stream at essentially all stations (Fig. 13).

The catch per unit effort shows significant differences in the occurrence of both P. vigil and T. crenata in each of the four sections (Table 16). T. crenata occurred 46 percent more frequently than P. vigil in section I. Both species showed marked increases in frequency of capture in section II as compared with other sections, with P. vigil exceeding T. crenata by 10.7 percent. P. vigil occurred extremely infrequently in the crab nets of section III and was totally absent in the collections in section IV. T. crenata exhibited a reduced frequency of capture in section III, but reoccurred most strongly in section IV where C/E = 1.0.

The decrease in dissolved oxygen at the bottom from stations 20 through 29 is highly suspect as a probably limiting factor to the horizontal distribution of P. vigil in the Canal proper (Table 7; Fig. 9). The lack of its occurrence in the stream area may result from the slightly lower salinities. On the average, bottom salinities in section IV are about 2 $^{o}/oo$ lower than those recorded in sections I, II, or III (Table 1). The species may be relatively more stenohaline and thus not able to tolerate the lower and more variable salinities found in the stream.

T. crenata, by contrast, seems to be readily abundant at all salinities encountered in this study area. Its reduced frequency of occurrence in section III is most likely the result of the low values of dissolved oxygen observed over a large portion of that section.

Scylla serrata, the samoan crab, was taken on only six occasions and was collected only from station 16 eastward and in the Manoa-Palolo Streams (Fig. 13). According to Kah Sin Ong (1964, 1966), this crab seeks areas of lower salinity, given a choice, and exhibits most rapid growth and lowest mortality, especially of the young, at salinities between 21 and 27 $^{o}/oo$.

Portunus sanguinolentus, the white crab, was recorded from three stations (Fig. 13).

Squilla oratoria, the mantis shrimp, occurred in the trawls in section I and at station 6. It was not taken elsewhere in the Canal or Stream (Fig. 13).

a. Vertical Distribution

A comparison of the occurrence of the two major species of Crustacea with the horizontal bathymetry of the Canal indicates the greatest concentration of Podophthalmus vigil at stations 4, 5, and 9-14, corresponding to depths of 2-1/2 to 3-1/2 m to less than 1 m, respectively. Thalamita was ubiquitous but was particularly prevalent in the shallow waters (1 to 1-1/2 m) at stations 12-19, 30, and at stream stations 31 and 33 (Fig. 13).

b. Seasonal Distribution

The seasonal distribution of P. vigil and T. crenata was examined by a comparison of the monthly catch per unit (Table 17). Two similar seasonal cycles were apparent for each species: a high catch per unit effort in the months of April, May, and June, and another in November and December.

c. Distribution Relative to Sex

One of the more interesting observations to arise during the course of this study has been the relative proportion of male and female crabs collected of these two species (Fig. 14; Table 18). The horizontal distribution of the crabs relative to sex reveals that, in nearly every section, male crabs were collected more frequently than female crabs. The percentage frequency of occurrence of male crabs based on the total number of both sexes recorded combining all methods of capture is illustrated in Table 18. In the case of T. crenata, male crabs only slightly outnumbered females in section I. Sections II, III, and IV yielded 65, 74, and 71 percent male crabs, respectively. An exception to the generally greater preponderance of male to female crabs occurred in section I where more P. vigil females were collected than males. The more usual high male ratio was present in section II where 71 percent of P. vigil collected were males. P. vigil, although present in only the first four stations of section III, continued to exhibit a high ratio, 67 percent, of male to female crabs.

Berried (egg-bearing) T. crenata females were collected from several stations but most frequently between stations 3-6. Except for two months, June and August, they were collected throughout the year, but were slightly more abundant in February. They ranged in width from 3.22 to 6.36 cm, with a median width of 5.48 cm and an arithmetic average width of 5.24 cm.

Berried P. vigil females were taken primarily between stations 8 and 13. Eight of them were taken in the summer months from May to July, and two in February. Their width ranged from 5.38 to 8.16 cm, with a median width of 6.66 cm and an arithmetic average of 6.78 cm.

d. Distribution Relative to Size

Crabs smaller than 3 cm in width were not generally retained by the collecting nets employed. For crabs 3 to 9 cm in width there was no apparent correlation between size and horizontal distribution for either of these two species.

A three-months moving total of the size range of T. crenata showed a slight decrease in the size of those captured during the months of May through August, 1971. A similar calculation for P. vigil indicated a slight decrease in size captured in June through August, 1971.

e. Distribution Relative to Salinity, Temperature, and Oxygen

With the exception of the region immediately adjacent to stations 22, 26, and 27, there was no area of the study which was not occupied by T. crenata. This would indicate that the physical parameters of salinity, temperature, and oxygen for most of the study are non-limiting to the euryhaline and eurythermal T. crenata. It is assumed that the low values of dissolved oxygen recorded at stations 22, 26, and 27 are responsible for the lack of their occurrence at those stations. By contrast, P. vigil is apparently distinctly limited in its eastward occupancy of the Canal by the low values of dissolved oxygen and low salinities previously discussed. Scylla serrata, although only rarely taken, was present only in regions of low salinities near storm drains or in the stream mouth. Squilla oratoria was collected almost exclusively in section I in an area of generally high salinities and saturated dissolved oxygen.

f. Distribution Relative to Tide

The calculated catch per unit effort over all sections of the Canal on incoming versus outgoing tides for P. vigil showed virtually no influence of tidal direction on their capture. T. crenata was taken slightly more frequently on an incoming tide (Table 19), however the difference was not significant.

3. Nekton (Fish)

Nekton, by definition, are those organisms capable of direct or purposeful, and to some extent, rapid locomotion.

Nekton in the Ala Wai may be divided into two general groups depending on their life style and food habits:

(1) the free, fast-swimming pelagic species such as kaku (barracuda), awa, awa awa, mullet, papio, and nehu;

(2) the bottom-dwelling, detritus and algae feeders such as the gobiids, lizardfish, and cardinalfish.

In the design of sampling methods and anlysis of data on the fish population of the Ala Wai Canal, special emphasis has been directed toward the ecological factors relevant to fish of recreational value.

a. Horizontal Distribution

Nineteen species of fish have been recorded from the Canal. Their horizontal distribution is illustrated in Figure 15. In addition, released aquarium fish, Molliensia and Lebistes, are found in sections III and IV, respectively. Of the eleven recreational species noted, awa (Chanos chanos), awa awa (Elops hawaiiensis), mullet (Mugil cephalus), papio Scomberoides santi-petri), kaku (Sphyraena barracuda), and Tilapia mozambique, occurred widely throughout the Canal and Stream in sufficient numbers to warrant labeling them as of prime recreational importance.

Elops hawaiiensis (awa awa) is fished from shore with hook and line using the small live Molliensia for bait. The fish are widely distributed throughout the Canal and were taken as far north (mauka) as stream station 32. They occurred most frequently around stations 13-19 in the vicinity of the confluence of the Manoa-Palolo streams with the canal proper.

Chanos chanos (awa) was one of the most frequently occurring recreational species and was second only to E. hawaiiensis in its wide range of occurrence. Chanos occurred most frequently and in greatest numbers in section III. It is basically a vegetarian feeding on algae and for this reason is a difficult species to catch on hook and line. On at least one occasion it was observed being caught on an algae-baited hook in the adjoining Ala Wai Yacht Harbor. It was taken in the gill nets from stations 1 through 34.

Mugil cephalus (mullet) were taken from stations 2 through 28, but were definitely most common in a narrow range from stations 14 through 19. No mullet were taken from the Manoa-Palolo streams. Only rarely were local people observed fishing for them. On questioning, fishermen most frequently cited the increase in Tilapia as a "cause" of the decrease in mullet fishing, i.e., Tilapia steal their bait. Many mullet fishermen had switched to the larger and more easily caught awa awa.

b. Size Distribution

All fish collected were measured to standard length to provide information on the size distribution of each species within the Canal (Table 20). The information presented provides a current "best estimate" of the size range of the 19 identifiable species of fish present in the Canal as collected by the otter trawl and gill nets. The relative catch per unit effort of each method is itemized in Table 21. As would be expected, the greater catch ratios are found with the smaller fish. It is most difficult to determine the significance of these numbers inasmuch as the collecting techniques available, when combined with the variation in habitat and ecology, i.e., pelagic versus benthic, may create sufficient differences in capture that size distribution as well as presence or absence estimates may be unreliable. For example, it is well established that young kaku (Sphyraena barracuda) are commonly found in estuarine environments, yet from this study one could conclude that only the adults or juveniles greater than about 20 cm in standard length might be expected to occur in the Canal. Apparently their pelagic life style (a capability for rapid locomotion) allows the smaller fish to escape the otter trawl and the slender body of the young would not be retained in the 2-1/2 inch stretch gill nets.

c. Seasonal Distribution

The seasonal distribution of the fish caught in the otter trawls and gill nets is illustrated in Tables 22 and 23, respectively. Of the twenty-one species recorded with these two methods of capture, six may be considered of prime importance from a recreational standpoint.

Chanos chanos (awa) showed a distinct seasonal trend, being present from June until December and disappearing completely during the spring, March-May.

Elops hawaiiensis (awa awa) was present in roughly the same frequency throughout the year.

Mugil cephalus (mullet) apparently is somewhat more common in January-March and less frequent or absent in the summer.

Scomberoides sancti-petri (papio) was taken from August through February and rarely to never taken the rest of the year.

Sphyraena barracuda (kaku) is similar in monthly occurrence to papio, being present in most months from July to February.

Tilapia mozambique was captured only in the months of February and March.

d. Distribution Relative to Salinity, Temperature, and Oxygen

Sampling techniques employed did not provide for a quantitative evaluation of the distribution of the twenty-one species of fish as a function of temperature, salinity, and oxygen. However, certain general conclusions may be drawn from a comparison of Figures 2, 6, 9 and 15.

Species of fish dwelling at or near the bottom, such as Apogon brachygrammus, Oxyurichthys lonchotus, and Saurida gracillis, to name a few, are noticeably absent in areas of low oxygen. T. mozambique was definitely more prevalent in the lower salinity Manoa Stream waters. The mid-water and surface dwelling, fast-swimming fish experienced little change in temperature, salinity, and oxygen in the well-mixed upper layers of the Canal. The temperature range is very narrow, approximately 2.5°C both horizontally and vertically; thus temperature per se was not indicated to be a limiting factor in the distribution of any of the fish collected.

e. Distribution Relative to Tide

A significant difference was noted in a few species in the relative catch per unit effort with regard to tidal direction (Tables 24, 25). Arothon hispides was taken almost twice as often on an incoming tide as compared with an outgoing tide. The greatest catch per unit effort was indicated for the zero tide condition where the catch per unit effort ratios yielded values as high as 12.8 for Apogon brachygrammus and several other species where catch per unit effort was greater than 1.0.

4. Stomach Content Analysis

Many of the species of fish recorded from the Canal, particularly those captured in the otter trawls, were too small or of socially unpopular species to be considered of direct recreational value. It was presumed that these smaller fish formed a significant percentage of the total food budget of many of the larger recreational species. To estimate the importance of these smaller species in the food chain of the recreational species, the contents of the stomachs of several of the popular recreational species of fish were analyzed.

a. Methods and Procedures

Stomachs were removed from fish and the contents washed into a graduated cylinder (centrifuge tube). Contents were allowed to settle for approximately 15 hours, then total volume was recorded. If the sample consisted of fish or large crustacea the total volume was given from the displacement volume. Samples containing plankton and algae were aliquoted as necessary to facilitate counting. Counts were made on 1-ml samples using the Sedgewich-Rafter counter and a 10X objective for diatoms and algae. Efforts were made toward consistency in settling times, aliquot methods, and counting techniques to minimize analysis errors.

b. Results and Discussion

Representatives of seven recreational species of fish were selected for stomach content analysis in order to estimate the relative importance of the various organisms to the food chain of these species. The stomachs of Albula vulpes (o'io) (1), Sphyraena barracuda (kaku) (3), and Caranx sp. (papio) (2), contained fragments of such items as fish and fish scales, polychaetes, shrimp, and crab parts. A large number of stomachs were available for investigation from Elops hawaiiensis (awa awa) (35), Chanos chanos (awa) (16), Scomberoides sancti-petri (papio) (8), and Mugil cephalus (mullet (6). The results of these examinations indicate that Elops and Scomberoides feed almost exclusively on small fish, predominantly gobies (Gobiidae), Oxyurichthys lonchotus, Bathygobius fuscus, and Stolephorus purpureus (nehu), with only an occasional small shrimp or crab. Forty-two gobies and 24 nehu were taken from the 35 Elops examined. These small fish ranged in length from 4.0 to 7.5 cm (average 5.8 cm) for the gobies, to 3.0 to 5.2 cm (average 4.1 cm) for the nehu. Gobies were consumed by *Elops* in approximately a 3:1 ratio over nehu in sections I and II. In section III the selection was reversed. Eight nehu were taken from the four *Elops'* stomachs examined but no gobies were present. This probably reflects the decrease in occurrence of the bottom-dwelling gobies in section III due to the low values of oxygen frequently present in that area, and the utilization by *Elops* of the pelagic, surface-dwelling nehu.

The fused pelvic fins of the gobiids helped in identifying larger fragments of that family. The pointed caudal fin of *Oxyurichthys lonchotus* was helpful in the identification of fragments of that species.

Nehu were more frequently selected (than gobies) by *Scomberoides*. Other small fish observed in the stomachs were too badly decomposed for positive identification but may have been apogonids (*Apogon brachygrammus*) as they are very abundant throughout the Canal.

Chanos stomachs contained varying amounts of blue-green algae and diatoms. At least six of the sixteen *Chanos* investigated contained significant numbers of zooplankters, particularly copepods. There was no apparent correlation between station of capture and stomach contents of *Chanos*.

The contents of the mullet stomachs were limited to plant material, both algae and diatoms.

IV. SUMMARY

(1) The Ala Wai Canal is a long, man-made, estuarine canal of considerable use as a recreational facility in the center of Waikiki, Hawaii, a densely populated urban area.

(2) Measurements of salinity, temperature, and oxygen in the surface waters indicate wide daily variations equalling or exceeding seasonal variation and surpassing horizontal variability except in areas immediately adjacent to maximum storm drain or stream runoff.

(3) Measurements of salinity and temperature in the bottom waters show little variability either daily or seasonally except in areas as noted above. Oxygen values in the eastern end of the Canal show a marked and significant reduction due to the restricted circulation in that area resulting from the bottom topography.

(4) Tidal and wind effects are major factors influencing the distribution of temperature, salinity, and oxygen in the Canal.

(5) A profuse and varied zooplankton fauna is present in the Ala Wai Canal. With minor exceptions, there is little horizontal or seasonal variability in the frequency of occurrence or numbers present of the zooplankters.

(6) In total numbers of species, the holoplankters and meroplankters were approximately evenly divided. In numbers of individuals and volume the holoplankters frequently exceeded the meroplankters by 2:1, primarily due to the abundance of copepods.

(7) Copepods were the single most abundant and universally occurring zooplankter.

(8) Two species of crab, Thalamita crenata and Podophthalmus vigil, formed more than 95 percent of all macrocrustacea captured. Both species are heavily fished in the Canal by the local people.

(9) Thalamita crenata is ubiquitous in its distribution in the Canal and Stream. Podophthalmus vigil is restricted to the area seaward (makai) of station 20.

(10) Male crabs of both species were taken significantly more frequently than female. Berried Podophthalmus vigil occurred most frequently in May through July. Berried Thalamita crenata occurred most frequently in February, but were taken in all months except June and August.

(11) The low oxygen values at specific stations in the mauka or eastern end of the Canal are cited as cause for the limited distribution of Crustacea at these stations.

(12) Twenty-one species of fish were recorded from the Canal, of which eleven are considered of recreational importance.

(13) Elops hawaiiensis (awa awa), Chanos chanos (awa), Mugil cephalus (mullet) and Tilapia mozambique are the most abundant recreational species.

(14) Elops hawaiiensis (awa awa) is heavily fished by the local people using the released aquarium fish, Molliensia, for bait.

(15) Chanos chanos (awa), although readily abundant for ten months of the year and an excellent food fish, is rarely if ever taken by the local people on hook and line as it is primarily an algae feeder.

(16) Stomach contents of seven of the major recreational species were examined. The gobiids, nehu, and to a lesser degree apogonids (cardinalfish) form the primary food source of the carnivorous fishes. Crabs and shrimp were rarely present in the stomach-content samples and are considered to be of little or no importance in their diet. In addition to the algae and diatoms normally utilized by the herbivores, about one-third of the Chanos stomachs examined contained significant numbers of copepods.

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APPENDIX A

Tables 1 - 25

Table 1. Average Surface and Bottom Salinity ($^{o}/oo$)

STATION	MEAN SURFACE	MEAN BOTTOM
1	20.80	32.76
2	22.39	34.87
3	21.65	34.61
4	25.40	31.63
5	20.55	34.54
6	28.02	34.47
7	19.17	32.14
8	20.30	34.45
9	22.77	33.70
10	23.88	34.16
11	18.74	32.14
12	16.87	34.27
13	21.08	33.75
14	25.18	34.14
15	24.16	33.33
16	28.30	33.50
17	20.98	28.90
18	20.37	34.30
19	25.13	33.78
20	23.60	33.72
21	26.13	33.89
22	22.19	34.61
23	28.80	34.30
24	23.30	34.06
25	26.71	33.90
26	28.01	34.26
27	29.26	34.15
28	27.23	34.25
29	28.71	31.41
30	32.80	34.20
31	25.98	33.50
32	19.28	33.45
33	21.85	32.54
34	21.70	33.15
35	24.21	32.74
36	30.03	32.37
37	25.39	25.28
38	24.98	32.37
AVERAGE		
SECTIONS		
I	22.16	33.68
II	22.45	33.24
III	25.86	33.91
IV	24.18	31.92

Table 2. Average Monthly Surface and Bottom Salinity (^{o}/oo), Standard Deviation, and Number of Observations in Sections I-IV

	SECTION 1			SECTION 2			SECTION 3			SECTION 4		
	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.
						SURFACE						
FEB	0.0	0.0	0	21.70	9.50	2	0.0	0.0	0	0.0	0.0	0
MAR	28.83	0.24	4	29.49	1.40	8	32.05	2.03	7	29.01	3.22	4
APR	24.51	2.00	7	21.61	6.12	7	33.49	1.92	8	27.12	4.33	6
MAY	25.26	4.77	7	23.24	5.95	14	30.68	2.88	19	27.01	3.91	13
JUNE	28.67	3.87	7	27.92	2.54	12	31.64	1.63	15	27.08	3.24	11
JULY	11.95	8.79	6	12.11	7.94	7	14.91	8.40	16	17.55	7.94	4
AUG	26.85	2.73	6	26.88	1.49	9	31.58	3.06	9	25.79	5.21	9
SEPT	23.22	3.61	6	23.14	6.43	9	29.28	5.03	9	25.15	8.92	6
OCT	19.63	5.46	6	24.91	5.82	7	30.58	4.01	15	22.80	6.30	3
NOV	22.80	0.0	1	5.00	0.0	1	5.30	0.37	2	1.20	0.0	0
DEC	14.93	10.61	6	17.94	12.31	8	23.36	11.90	10	11.36	9.56	5
JAN	10.55	8.09	4	4.24	4.31	9	6.98	8.67	6	8.20	8.10	2
FEB	19.02	8.45	5	24.38	6.43	10	28.16	8.63	9	29.49	2.14	7
MAR	25.60	0.0	1	24.90	0.0	1	30.05	2.35	2	28.33	3.47	3
APR	18.35	6.15	2	25.70	0.0	1	29.60	0.0	1	12.20	0.0	1
						BOTTOM						
FEB	0.0	0.0	0	34.20	0.35	2	0.0	0.0	0	0.0	0.0	0
MAR	35.40	0.80	4	34.54	1.43	8	35.07	0.59	9	34.03	0.70	3
APR	35.58	0.19	10	33.06	7.24	7	35.23	0.26	6	33.92	0.44	6
MAY	34.61	0.36	7	34.02	0.36	12	34.02	0.71	16	31.58	2.35	6
JUNE	34.53	0.21	6	34.30	0.38	12	34.01	0.48	14	32.49	1.24	9
JULY	34.62	0.13	6	34.27	0.17	7	33.98	0.67	17	31.30	2.27	4
AUG	34.35	0.25	6	33.82	0.61	9	33.87	0.49	9	32.53	0.54	7
SEPT	34.60	0.16	6	33.83	0.65	9	34.02	0.39	10	31.90	2.43	4
OCT	34.55	0.13	6	34.25	0.24	6	34.13	0.16	20	33.57	0.38	3
NOV	34.60	0.0	1	33.00	0.50	2	33.50	0.12	2	32.50	0.0	1
DEC	34.68	0.13	6	34.18	0.33	6	34.19	0.20	10	33.62	0.35	5
JAN.	29.38	9.80	5	21.06	13.66	7	30.31	9.04	8	16.85	16.75	2
FEB	33.62	1.05	5	32.94	1.42	8	33.48	1.00	9	32.70	0.24	2
MAR	24.80	0.0	1	34.20	0.0	1	34.00	0.10	2	33.30	0.0	1
APR	33.55	0.85	2	33.40	0.0	1	32.60	0.0	1	29.00	0.0	1

Table 3. Average Surface and Bottom Salinity ($^o/oo$) on an Incoming and Outgoing Tide at Each Station

	INCOMING		OUTGOING	
STATION	MEAN SURFACE	MEAN BOTTOM	MEAN SURFACE	MEAN BOTTOM
1	18.61	32.11	25.72	34.37
2	24.97	34.94	19.33	34.63
3	21.87	34.75	22.00	33.98
4	25.00	30.20	26.20	34.50
5	23.82	34.47	18.22	34.82
6	28.37	34.37	27.30	34.65
7	19.47	30.51	13.90	34.47
8	21.87	34.73	15.60	33.60
9	24.27	34.11	20.15	33.12
10	22.87	34.27	25.40	34.00
11	26.34	33.98	12.63	34.30
12	13.47	34.33	19.42	34.22
13	23.03	33.73	17.90	33.72
14	29.20	34.25	26.35	34.85
15	22.20	33.85	30.05	32.30
16	26.63	33.50	--	--
17	23.33	31.54	23.55	34.25
18	--	--	20.37	34.30
19	26.89	33.67	32.20	34.20
20	28.-2	34.20	18.55	33.05
21	28.32	34.20	29.38	33.72
22	19.67	34.52	25.70	34.60
23	31.15	34.32	28.87	34.27
24	32.20	34.35	5.00	33.60
25	28.46	33.91	28.53	34.37
26	28.75	33.90	27.27	34.48
27	29.70	34.17	28.10	34.17
28	27.70	34.50	33.20	34.30
29	31.54	33.87	24.30	26.97
30	32.80	33.30	--	35.10
31	24.85	33.20	24.80	34.00
32	25.03	33.90	12.15	32.70
33	18.16	32.00	26.96	33.96
34	22.10	33.20	20.50	33.00
35	25.90	32.07	20.36	33.45
36	29.16	32.37	34.40	--
37	27.54	29.72	23.85	32.70
38	24.98	32.37	--	--

Table 4. Average Surface and Bottom Temperature (°C)

STATION	MEAN SURFACE	MEAN BOTTOM
1	26.48	25.97
2	26.34	25.71
3	26.65	26.22
4	27.27	28.23
5	26.62	26.11
6	27.12	26.32
7	26.07	26.15
8	25.90	25.87
9	28.06	27.17
10	28.38	27.18
11	25.89	26.29
12	26.59	26.88
13	26.98	26.92
14	27.27	26.70
15	27.51	27.13
16	26.80	27.60
17	26.62	26.24
18	27.22	26.83
19	27.12	26.86
20	27.88	26.94
21	27.75	26.86
22	26.86	26.56
23	28.01	26.98
24	27.85	27.00
25	27.89	26.75
26	27.73	27.01
27	27.98	26.90
28	27.43	26.52
29	27.32	26.66
30	27.75	29.17
31	27.44	27.52
32	27.40	27.25
33	28.23	27.74
34	27.90	27.45
35	27.29	27.05
36	28.38	27.73
37	27.37	27.56
38	27.04	27.57

Table 5. Monthly Average Surface and Bottom Temperature (°C), Standard Deviation, and Number of Observations in Sections I-IV

	SECTION 1			SECTION 2			SECTION 3			SECTION 4			OVER ALL SECTIONS
	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MONTHLY AVERAGE TEMP.
SURFACE													
FEB	0.0	0.0	0	22.50	0.50	2	0.0	0.0	0	0.0	0.0	0	
MAR	25.68	0.39	4	26.25	0.71	8	26.50	0.80	7	27.34	0.66	4	26.16
APR	26.29	0.94	7	25.96	1.46	7	26.54	1.08	8	27.97	0.39	6	26.64
MAY	26.64	0.76	7	26.71	0.76	14	27.90	0.74	19	27.50	0.49	13	27.18
JUNE	27.43	0.56	7	27.92	0.49	12	28.18	0.90	15	28.84	0.82	11	28.06
JULY	27.90	0.48	6	28.11	0.67	7	28.51	0.53	16	28.72	1.63	4	28.31
AUG	28.37	0.63	6	29.06	0.50	9	29.09	0.70	9	28.92	0.52	9	28.81
SEPT	28.30	0.88	6	29.09	1.03	9	30.13	1.23	9	29.15	0.48	6	29.14
OCT	27.34	1.17	7	27.86	1.08	8	29.17	0.84	15	28.47	0.95	3	28.21
NOV	25.20	0.10	2	26.07	1.03	3	26.12	0.46	4	24.77	0.50	3	25.54
DEC	23.65	0.64	6	24.19	0.54	8	25.59	1.10	10	23.72	0.94	5	24.28
JAN	22.97	1.93	4	22.22	2.07	8	22.28	2.38	6	22.80	3.10	2	22.55
FEB	25.86	0.91	5	27.30	0.78	10	27.28	0.45	9	27.96	1.26	7	27.10
MAR	31.40	0.0	1	25.30	0.0	1	25.60	0.10	2	25.53	0.29	3	26.95
APR	25.65	0.25	2	27.00	0.0	1	27.40	0.0	1	26.20	0.0	1	26.56
BOTTOM													
FEB	24.90	0.0	1	25.90	3.35	6	0.0	0.0	0	0.0	0.0	0	
MAR	24.57	0.10	4	25.52	0.65	8	25.51	1.51	9	26.27	0.66	3	
APR	25.26	0.45	10	25.73	1.52	7	25.49	0.45	6	27.08	0.86	6	
MAY	25.91	0.32	7	26.46	0.52	12	26.84	0.50	16	27.35	0.74	6	
JUNE	26.50	0.29	6	27.21	0.48	12	27.49	0.61	14	27.99	0.47	9	
JULY	27.22	0.27	6	28.04	0.41	7	28.05	0.42	17	28.97	0.74	4	
AUG	27.30	0.41	6	27.94	0.51	9	27.86	0.31	9	28.53	0.59	7	
SEPT	27.12	0.33	6	28.57	1.16	9	28.25	0.56	10	29.25	1.02	4	
OCT	27.20	0.41	7	27.56	0.67	7	27.83	0.34	20	27.53	0.33	3	
NOV	26.30	0.30	2	26.85	0.45	4	26.82	0.11	4	26.83	0.78	3	
DEC	25.22	0.51	6	25.62	0.38	6	25.54	0.60	10	25.82	0.61	5	
JAN	24.00	0.36	5	23.73	2.02	6	24.29	1.10	8	22.85	3.51	2	
FEB	25.36	0.50	5	26.02	0.62	8	25.68	0.48	9	28.25	1.65	2	
MAR	34.20	0.0	1	25.20	0.0	1	25.15	0.15	2	25.30	0.0	1	
APR	25.70	0.20	2	26.90	0.0	1	26.40	0.0	1	26.90	0.0	1	

Table 6. Average Surface and Bottom Temperature (°C) on an Incoming and Outgoing Tide at Each Station

	INCOMING		OUTGOING	
STATION	MEAN SURFACE	MEAN BOTTOM	MEAN SURFACE	MEAN BOTTOM
1	26.38	25.89	26.66	26.12
2	26.33	25.62	27.60	26.13
3	26.54	26.39	26.97	26.46
4	29.15	29.85	23.50	25.00
5	26.78	26.02	27.54	26.64
6	26.70	25.90	27.95	27.15
7	26.56	25.77	26.72	26.12
8	25.87	25.80	26.00	26.10
9	28.23	27.56	27.77	26.72
10	27.43	26.70	29.80	27.90
11	27.67	26.58	26.20	26.57
12	25.57	27.02	27.60	26.76
13	27.63	27.34	26.02	26.40
14	28.00	27.22	26.70	26.30
15	27.03	27.35	28.95	26.83
16	28.47	27.60	--	--
17	27.37	26.94	27.40	27.45
18	--	0.0	27.22	26.83
19	27.65	27.02	28.25	27.25
20	27.32	27.08	27.70	26.10
21	27.65	26.60	28.36	27.17
22	27.30	26.90	25.95	25.82
23	27.90	26.60	28.21	27.26
24	27.90	26.00	25.50	27.00
25	27.77	26.89	28.63	27.21
26	27.90	27.37	27.56	26.80
27	28.45	27.11	27.38	26.82
28	25.50	25.15	28.50	27.00
29	27.76	26.82	27.02	26.62
30	27.75	29.10	--	29.24
31	27.65	27.74	27.17	27.25
32	28.33	27.23	26.75	27.90
33	27.76	27.60	28.97	28.10
34	27.73	27.07	28.40	28.60
35	27.59	26.73	26.74	27.38
36	28.50	27.73	27.80	--
37	28.15	29.57	27.43	27.45
38	27.04	27.57	--	--

Table 7. Average Surface and Bottom Oxygen (ppm)

STATION	MEAN SURFACE	MEAN BOTTOM
1	7.37	4.91
2	7.19	5.53
3	7.62	4.91
4	8.70	6.10
5	7.49	4.33
6	8.10	5.86
7	8.05	4.26
8	7.62	4.77
9	9.09	5.45
10	9.95	4.72
11	8.40	5.29
12	7.77	5.01
13	7.71	4.62
14	9.75	5.82
15	9.73	8.00
16	10.20	6.27
17	9.43	7.39
18	10.28	6.27
19	8.97	3.95
20	9.44	2.09
21	10.08	2.18
22	9.04	1.09
23	7.92	1.37
24	7.47	2.87
25	7.67	1.09
26	6.72	1.80
27	7.92	0.58
28	6.30	1.23
29	6.66	3.57
30	7.87	14.00
31	10.28	6.96
32	10.02	7.50
33	10.84	8.55
34	11.60	7.15
35	10.36	7.37
36	12.44	8.30
37	9.19	7.73
38	11.57	9.55

Table 8. Monthly Average Surface and Bottom Oxygen (ppm), Standard Deviation, and Number of Observations in Sections I-IV

	SECTION 1			SECTION 2			SECTION 3			SECTION 4		
	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.	MEAN	STD. DEV.	NO. OF OBS.
						SURFACE						
FEB	0.0	0.0	0	6.75	0.05	2	0.0	0.0	0	0.0	0.0	0
MAR	8.40	0.0	1	9.10	0.53	4	9.18	1.19	5	12.02	2.52	4
APR	8.43	0.44	6	8.62	1.14	5	7.28	1.61	6	12.50	0.50	2
MAY	7.91	0.70	7	9.06	1.42	14	9.36	2.01	19	11.66	1.83	13
JUNE	7.35	1.02	6	8.60	0.83	10	7.67	1.84	12	10.91	1.69	10
JULY	6.63	0.72	6	7.79	2.06	7	7.04	2.45	16	11.17	3.88	4
AUG	8.32	1.91	6	10.44	3.13	9	8.42	2.63	9	11.17	2.79	9
SEPT	7.37	1.52	6	8.09	2.01	9	8.94	1.52	9	9.82	2.88	6
OCT	7.48	1.19	6	8.74	1.13	7	8.06	1.00	14	10.40	3.93	3
NOV	5.90	0.20	2	5.95	0.31	2	7.30	1.13	5	6.83	0.90	3
DEC	7.70	0.50	6	8.64	1.48	8	9.05	3.21	10	8.36	0.92	5
JAN	5.33	1.89	3	7.91	0.88	8	8.35	1.62	6	9.20	0.60	2
FEB	6.65	0.69	4	9.04	1.99	9	7.31	2.25	8	9.03	2.14	7
MAR	10.50	0.0	1	9.40	0.0	1	5.80	0.20	2	10.10	1.37	3
APR	8.45	2.75	2	10.60	0.0	1	5.10	0.0	1	5.90	0.0	1
						BOTTOM						
FEB	5.50	0.0	1	7.55	2.09	6	0.0	0.0	0	0.0	0.0	0
MAR	5.60	0.0	1	5.87	1.06	4	6.37	4.88	6	11.0	2.05	3
APR	6.09	0.90	7	7.62	3.62	4	2.85	2.06	4	9.10	0.0	2
MAY	6.51	1.40	7	5.52	1.23	12	3.16	2.87	16	10.82	2.25	6
JUNE	5.62	1.00	5	5.46	1.14	10	2.85	2.05	11	9.50	2.77	8
JULY	4.25	0.36	6	6.19	3.65	7	0.79	1.24	17	9.22	5.05	4
AUG	5.10	0.59	6	6.16	1.96	9	2.61	3.39	9	8.00	4.07	7
SEPT	3.76	0.90	6	4.21	1.69	9	1.19	1.27	10	5.42	2.33	4
OCT	4.40	0.61	6	4.17	0.97	6	1.09	1.39	19	4.03	0.09	3
NOV	5.55	0.85	2	2.10	0.85	2	0.80	0.67	4	4.00	0.93	3
DEC	5.52	0.59	6	4.87	2.64	6	2.43	1.43	10	5.36	2.36	5
JAN	4.33	0.45	3	5.90	4.66	5	2.10	2.33	7	5.10	0.90	2
FEB	2.77	1.48	4	4.83	1.80	7	1.29	0.63	8	7.13	0.85	3
MAR	5.70	0.0	1	3.10	0.0	1	0.70	0.10	2	7.20	0.0	1
APR	4.35	1.35	2	5.50	0.0	1	0.30	0.0	1	4.00	0.0	1

Table 9. Average Surface and Bottom Oxygen (ppm) on an Incoming and Outgoing Tide at Each Station

	INCOMING		OUTGOING	
STATION	MEAN SURFACE	MEAN BOTTOM	MEAN SURFACE	MEAN BOTTOM
1	7.51	4.99	7.07	4.75
2	7.78	5.79	5.17	4.80
3	7.71	5.07	7.30	3.72
4	9.65	6.30	6.80	5.70
5	7.77	4.47	6.73	4.20
6	8.30	6.40	7.80	5.05
7	9.17	4.02	7.22	3.94
8	7.57	4.97	7.80	4.20
9	8.72	4.82	9.83	6.40
10	8.80	4.60	11.10	4.85
11	9.43	5.91	6.43	3.17
12	7.95	4.07	7.53	5.95
13	7.68	5.27	7.90	3.65
14	9.35	5.90	10.15	5.75
15	9.98	7.93	9.10	8.07
16	9.77	6.27	--	--
17	9.61	7.78	9.50	3.70
18	--	0.0	10.23	6.27
19	9.22	4.50	8.15	2.85
20	9.48	2.13	12.80	1.80
21	10.56	2.41	10.02	1.76
22	9.72	0.87	8.50	1.50
23	8.37	1.89	7.24	1.20
24	7.77	4.60	8.10	0.0
25	7.83	1.19	7.53	0.98
26	6.20	2.96	7.25	1.11
27	7.57	0.48	8.50	0.75
28	6.00	0.80	6.70	1.40
29	7.07	3.09	6.68	4.92
30	7.87	0.0	--	14.00
31	10.84	7.95	9.05	5.97
32	10.13	7.93	9.95	8.50
33	9.48	7.87	13.05	9.57
34	11.67	6.20	11.40	10.00
35	11.49	9.90	8.92	4.68
36	11.55	8.30	16.00	--
37	9.79	10.25	9.10	3.55
38	11.57	9.55	--	--

Table 10. Percent Frequency of Occurrence of Zooplankton in Sections I-IV

	I	II	III	IV	Total No.	Total %
AMPHIPODS	7.7	18.8	9.1	15.0	14	12.6
ASCIDIAN LARVAE	61.5	15.6	9.1	0.0	24	21.6
CHAETOGNATHS	73.1	68.8	90.9	40.0	79	71.3
CIRRIPEDES	88.5	87.5	90.0	65.0	94	84.7
CLADOCERANS	0.0	0.0	6.1	0.0	2	1.8
COPEPOD NAUPLII	57.7	40.6	36.4	50.0	50	45.1
COPEPODS	96.2	87.5	100.0	95.0	105	94.6
CRAB MEGALOPAE	0.0	6.2	9.1	0.0	5	4.5
CRAB ZOEAE	73.1	78.1	84.8	60.0	84	75.6
DIPTERANS	3.8	0.0	3.0	0.0	2	1.8
ECHINODERM LARVAE	3.8	0.0	12.1	0.0	5	4.5
FISH EGGS	57.7	46.9	72.7	40.0	62	55.9
FISH LARVAE	38.5	37.5	42.4	35.0	43	38.7
INSECT LARVAE	0.0	3.1	3.0	5.0	3	2.7
ISOPODS	7.7	3.1	27.3	15.0	7	7.2
<u>LUCIFER</u> ADULTS	15.4	15.6	27.3	15.0	21	18.9
<u>LUCIFER</u> PROTOZOEAE	53.8	43.8	42.4	20.0	46	41.4
MEDUSAE	53.8	62.5	75.8	30.0	65	58.6
MITES	0.0	0.0	0.0	5.0	1	.9
MOLLUSCS	69.2	37.5	54.5	40.0	56	50.4
MYSIDS	7.7	0.0	0.0	0.0	2	1.8
NEMATODES	0.0	0.0	0.0	5.0	1	.9
<u>OIKOPLEURA</u>	15.4	6.2	3.0	5.0	8	7.2
OSTRACODS	7.7	9.4	18.2	15.0	14	12.6
POLYCHAETES	65.4	62.5	60.6	65.0	70	63.1
<u>PSEUDODIAPTOMUS</u>	34.6	28.1	24.2	20.0	30	27.0
SHRIMP	76.9	84.4	87.9	50.0	86	77.5
STOMATOPODS	15.4	0.0	6.1	0.0	6	5.4
Number of tows	26	32	33	20	11	

Table 11. Average Total Number of Zooplankton Per Section

	I	II	III	IV
AMPHIPODS	74	21	117	48
ASCIDIAN LARVAE	60	27	198	----
CHAETOGNATHS	555	337	1241	126
CIRRIPEDES	1859	3534	7117	5423
CLADOCERANS	----	----	7	----
COPEPOD NAUPLII	18217	2385	12297	3004
COPEPODS	9790	9862	12195	17784
CRAB MEGALOPAE	----	10	16	----
CRAB ZOEAE	1826	812	1560	443
DIPTERANS	16	----	16	----
ECHINODERM LARVAE	24	----	106	----
FISH EGGS	99	278	1011	462
FISH LARVAE	76	132	225	159
INSECT LARVAE	----	4	16	16
ISOPODS	16	50	64	54
<u>LUCIFER</u> ADULTS	153	206	216	173
<u>LUCIFER</u> PROTOZOEA	694	472	828	104
MEDUSAE	147	222	3707	175
MITES	----	----	----	32
MOLLUSCS	283	82	257	72
MYSIDS	32	----	----	----
NEMATODES	----	----	----	16
<u>OIKOPLEURA</u>	200	40	64	64
OSTRACODS	16	27	61	21
POLYCHAETES	464	284	1896	412
<u>PSEUDODIAPTOMUS</u>	28405	17	1837	132
SHRIMP	268	94	284	768
STOMATOPODS	42	----	160	----
Number of tows	26	32	33	20

Table 12. Number and Frequency of Occurrence of Organisms in Zooplankton Tows with the Three Mesh Sizes

	64μ		250μ		333μ	
	No.	%	No.	%	No.	%
AMPHIPODS	4	14.3	8	11.8	2	13.3
ASCIDIAN LARVAE	4	14.3	16	23.5	4	26.7
CHAETOGNATHS	9	32.2	56	82.4	13	86.6
CIRRIPEDES	22	78.6	57	83.8	15	100.0
CLADOCERANS	--	----	2	2.9	--	----
COPEPOD NAUPLII	27	96.5	19	27.8	4	26.7
COPEPODS	27	96.5	65	95.6	13	86.6
CRAB MEGALOPAE	--	----	5	7.3	--	----
CRAB ZOEAE	4	14.3	65	95.6	15	100.0
DIPTERANS	--	----	2	2.9	--	----
ECHINODERM LARVAE	4	14.3	1	1.5	--	----
FISH EGGS	6	21.4	45	66.2	11	73.4
FISH LARVAE	4	14.3	34	50.0	2	13.3
INSECT LARVAE	--	----	3	4.4	--	----
ISOPODS	--	----	6	8.8	1	6.7
<u>LUCIFER</u> ADULTS	--	----	20	29.4	1	6.7
<u>LUCIFER</u> PROTOZOEAE	5	17.8	34	50.0	7	46.0
MEDUSAE	10	35.7	41	60.3	13	86.6
MITES	--	----	1	1.5	--	----
MOLLUSCS	10	35.7	41	60.3	6	40.0
MYSIDS	--	----	1	1.5	1	6.7
NEMATODES	--	----	1	1.5	--	----
<u>OIKOPLEURA</u>	--	----	6	8.8	2	13.3
OSTRACODS	9	32.2	5	7.3	--	----
POLYCHAETES	26	92.7	39	57.4	6	40.0
<u>PSEUDODIAPTOMUS</u>	2	7.1	23	33.8	5	33.4
SHRIMP	3	10.7	68	100.0	15	100.0
STOMATOPODS	--	----	6	8.8	--	----
Number of tows	28		68		15	

Table 13. Percent Frequency of Occurrence of Organisms in Zooplankton Tows By Month

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
AMPHIPODS	---	---	---	40.0	16.7	28.6	25.0	---	16.7	7.7	20.0	7.1	12.5
ASCIDIAN LARVAE	---	---	42.8	40.0	33.3	28.6	25.0	42.8	---	30.8	20.0	---	37.5
CHAETOGNATHS	100.0	80.0	100.0	100.0	100.0	100.0	75.0	100.0	66.7	46.2	46.7	35.7	75.0
CIRRIPEDES	80.0	100.0	100.0	100.0	100.0	57.1	75.0	85.7	83.3	100.0	66.7	78.6	87.5
CLADOCERANS	---	---	---	---	---	---	---	28.6	---	---	---	---	---
COPEPOD NAUPLII	---	50.0	42.8	---	---	---	---	---	33.3	69.2	93.3	78.6	75.0
COPEPODS	100.0	90.0	100.0	80.0	83.3	100.0	100.0	100.0	100.0	92.3	86.7	100.0	100.0
CRAB MEGALOPAE	40.0	---	---	---	---	---	---	---	---	---	---	14.3	12.5
CRAB ZOEAE	100.0	100.0	100.0	100.0	100.0	100.0	100.0	85.7	66.7	53.8	46.7	50.0	62.5
DIPTERANS	---	---	---	---	---	---	---	---	---	7.7	---	7.1	---
ECHINODERM LARVAE	---	---	---	---	---	14.3	---	---	---	7.7	---	7.1	25.0
FISH EGGS	60.0	60.0	85.7	60.0	66.7	71.4	75.0	71.4	83.3	53.8	26.7	21.4	62.5
FISH LARVAE	40.0	20.0	28.6	20.0	83.3	57.1	37.5	71.4	66.7	38.5	26.7	21.4	50.0
INSECT LARVAE	---	---	---	---	33.3	---	---	14.3	---	---	---	---	---
ISOPODS	---	20.0	---	---	16.7	---	12.5	---	---	7.7	---	7.1	12.5
LUCIFER ADULTS	20.0	20.0	---	---	16.7	14.3	---	42.8	16.7	7.7	26.7	21.4	50.0
LUCIFER PROTOZOEAE	40.0	---	71.4	80.0	50.0	28.6	12.5	71.4	16.7	15.4	53.3	57.1	62.5
MEDUSAE	80.0	50.0	100.0	80.0	66.7	42.8	75.0	57.1	50.0	53.8	33.3	50.0	75.0
MITES	---	---	---	---	---	---	---	---	---	---	---	7.1	---
MOLLUSCS	40.0	20.0	57.1	40.0	66.7	42.8	75.0	57.1	33.3	69.2	33.3	57.1	62.5
MYSIDS	---	---	14.3	20.0	---	---	---	---	---	---	---	---	---
NEMATODES	---	---	---	---	16.7	---	---	---	---	---	---	---	---
OIKOPLEURA	---	---	28.6	20.0	16.7	14.3	12.5	---	16.7	---	---	---	12.5
OSTRACODS	---	---	---	---	16.7	14.3	---	14.3	---	7.7	20.0	42.8	12.5
POLYCHAETES	60.0	50.0	28.6	20.0	66.7	28.6	25.0	71.4	83.3	92.3	86.7	64.3	100.0
PSEUDODIAPTOMUS	40.0	---	85.7	20.0	16.7	71.4	25.0	42.8	16.7	7.7	---	21.4	62.5
SHRIMP	100.0	60.0	85.7	100.0	100.0	85.7	100.0	100.0	83.3	53.8	60.0	50.0	62.5
STOMATOPOD	---	---	---	---	---	14.3	---	---	---	15.4	6.7	7.1	12.5
Number of tows	5	10	7	5	6	7	8	7	6	13	15	14	8

Table 14. Log of the Geometric Mean of the Total Numbers of Zooplankton by Month

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
AMPHIPODS	---	---	---	1.05	1.20	1.20	1.96	---	1.30	1.90	1.86	1.51	.90
ASCIDIAN LARVAE	---	---	1.16	2.16	1.05	1.49	1.74	.70	---	1.66	1.92	---	1.61
CHAETOGNATHS	2.22	2.05	1.73	1.99	1.84	2.74	2.74	1.79	2.30	2.80	1.85	2.22	2.10
CIRRIPEDES	2.90	1.96	2.67	2.38	2.59	4.25	3.75	3.03	3.31	2.99	2.33	2.98	2.79
CLADOCERANS	---	---	---	---	---	---	---	.84	---	---	---	---	---
COPEPOD NAUPLII	---	2.27	.90	---	---	---	---	---	3.85	3.88	3.35	3.61	2.86
COPEPODS	2.71	3.08	1.73	1.47	3.81	3.82	4.02	3.49	3.56	3.58	3.43	3.86	4.14
CRAB MEGALOPAE	.90	---	---	---	---	---	---	---	---	---	---	1.20	1.20
CRAB ZOEAE	2.87	2.26	2.02	3.09	2.08	3.13	2.48	2.59	2.23	2.56	2.39	2.94	2.99
DIPTERANS	---	---	---	---	---	---	---	---	---	1.20	---	1.20	---
ECHINODERM LARVAE	---	---	---	---	---	1.38	---	---	---	1.51	---	1.51	2.26
FISH EGGS	1.61	1.99	1.82	2.06	1.87	3.00	2.60	2.53	2.14	2.41	2.09	2.21	2.05
FISH LARVAE	1.51	2.00	---	1.20	1.43	1.55	2.19	1.99	2.09	1.94	1.81	1.80	1.32
INSECT LARVAE	---	---	---	---	1.20	---	---	.60	---	---	---	---	---
ISOPODS	---	1.70	---	---	1.68	---	1.81	---	---	1.20	---	1.81	1.20
<u>LUCIFER</u> ADULTS	1.68	2.00	---	---	1.20	1.81	---	1.29	1.38	1.51	2.38	2.49	1.93
<u>LUCIFER</u> PROTOZOEAE	1.75	---	1.42	1.62	1.99	2.64	2.28	1.00	.90	1.81	2.32	2.60	2.51
MEDUSAE	2.65	2.11	2.54	1.75	1.51	1.98	2.71	2.04	1.40	1.97	1.54	2.33	2.05
MITES	---	---	---	---	---	---	---	---	---	---	---	1.51	---
MOLLUSCS	1.85	1.94	1.68	1.51	2.17	1.87	2.05	1.08	1.20	2.47	1.93	1.86	1.83
MYSIDS	---	---	1.51	1.51	---	---	---	---	---	---	---	---	---
NEMATODES	---	---	---	---	1.20	---	---	---	---	---	---	---	---
<u>OIKOPLEURA</u>	---	---	1.58	2.74	.90	1.38	1.81	---	1.81	---	---	---	1.85
OSTRACODS	---	---	---	---	1.20	1.81	---	.78	---	2.02	1.51	1.41	1.20
POLYCHAETES	1.10	2.05	1.38	1.20	1.32	1.29	1.59	1.37	1.74	2.22	2.70	2.73	2.60
<u>PSEUDODIAPTOMUS</u>	.90	---	1.47	1.38	1.60	1.94	2.05	1.46	1.20	4.30	---	1.92	3.28
SHRIMP	1.59	1.96	1.49	1.78	1.44	2.08	1.98	1.47	1.44	2.31	2.04	2.36	2.65
STOMATOPODS	---	---	---	---	---	1.38	---	---	---	1.74	1.81	2.41	1.51
Number of tows	5	10	7	5	6	7	8	7	6	13	15	14	8

Table 15. Percent Occurrence of Zooplankton on an Incoming and Outgoing Tide by Section

	I		II		III		IV		TOTAL NO.		TOTAL %	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
AMPHIPODS	8.3	7.7	17.6	18.2	4.8	12.5	8.3	0.0	6	4	9.7	10.8
ASCIDIAN LARVAE	75.0	53.8	11.8	18.2	14.3	0.0	0.0	0.0	14	9	22.6	24.3
CHAETOGNATHS	83.3	61.5	70.6	72.8	95.2	87.5	41.7	40.0	47	25	75.8	67.6
CIRRIPEDES	83.3	92.3	94.1	81.8	90.5	100.0	83.3	20.0	55	30	88.7	81.1
CLADOCERANS	0.0	0.0	0.0	0.0	4.8	12.5	0.0	0.0	1	1	1.6	2.7
COPEPOD NAUPLII	50.0	61.5	41.2	36.4	38.1	25.0	33.3	60.0	25	17	40.3	45.9
COPEPODS	91.7	100.0	88.2	90.9	100.0	100.0	100.0	80.0	59	35	95.2	94.6
CRAB MEGALOPAE	0.0	0.0	5.9	9.1	9.5	12.5	0.0	0.0	3	2	4.8	5.4
CRAB ZOEAE	83.3	61.5	88.2	63.6	81.0	100.0	75.0	40.0	51	25	82.2	67.6
DIPTERANS	8.3	0.0	0.0	0.0	0.0	12.5	0.0	0.0	1	1	1.6	2.7
ECHINODERM LARVAE	8.3	0.0	0.0	0.0	14.3	12.5	0.0	0.0	4	1	6.4	2.7
FISH EGGS	75.0	46.2	58.8	36.4	66.7	87.5	50.0	40.0	39	19	62.9	51.4
FISH LARVAE	41.7	38.5	29.4	54.5	38.1	62.5	58.3	0.0	25	16	40.3	43.2
INSECT LARVAE	0.0	0.0	5.9	0.0	4.8	0.0	8.3	0.0	3	0	4.8	0.0
ISOPODS	16.7	0.0	5.9	0.0	0.0	0.0	25.0	0.0	6	0	9.7	0.0
<u>LUCIFER</u> ADULTS	8.3	23.1	11.8	27.3	28.6	25.0	16.7	0.0	11	8	17.7	21.6
<u>LUCIFER</u> PROTOZOEAE	58.3	53.8	47.0	45.4	42.8	50.0	16.7	20.0	26	17	41.9	45.9
MEDUSAE	75.0	38.5	82.4	27.3	71.4	87.5	33.3	40.0	42	17	67.7	45.9
MITES	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	1	0	1.6	0.0
MOLLUSCS	75.0	69.2	41.2	36.4	52.4	50.0	50.0	40.0	33	19	53.2	51.4
MYSIDS	8.3	7.7	0.0	0.0	0.0	0.0	0.0	0.0	1	1	1.6	2.7
NEMATODES	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	1	0	1.6	0.0
<u>OIKOPLEURA</u>	25.0	7.7	11.8	0.0	0.0	0.0	0.0	20.0	5	2	8.1	5.4
OSTRACODS	0.0	15.4	11.8	9.1	19.0	12.5	8.3	0.0	7	4	11.3	10.8
POLYCHAETES	66.7	61.5	52.9	63.6	61.9	75.0	66.7	40.0	38	23	61.3	62.2
<u>PSEUDODIAPTOMUS</u>	66.7	7.7	35.3	27.3	28.6	25.0	25.0	20.0	23	7	37.1	18.9
SHRIMP	91.7	69.2	94.1	81.8	71.4	100.0	41.7	60.0	47	40	75.8	78.4
STOMATOPODS	25.0	7.7	0.0	0.0	4.8	0.0	0.0	0.0	4	1	6.4	2.7
Number of tows	12	13	17	11	21	8	12	5	62	37		

Table 16. Catch Per Unit Effort of *P. vigil* and *T. crenata* by Section

Section	Number Nets Set	*Podophthalmus vigil* Number Collected	*Podophthalmus vigil* Catch/Unit Effort	*Thalamita crenata* Number Collected	*Thalamita crenata* Catch/Unit Effort
I	61	13	.213	19	.311
II	127	65	.512	58	.457
III	150	4	.027	42	.28
IV	70	0	0	70	1.0
Total Number	408	82	.201	189	.463

Table 17. Catch Per Unit Effort of *P. vigil* and *T. crenata* by Month

	Number Nets Set	*Podophthalmus vigil* Number Collected	*Podophthalmus vigil* Catch/Unit Effort	*Thalamita crenata* Number Collected	*Thalamita crenata* Catch/Unit Effort
October 1969	5	1	.2	1	.2
November 1969	16	0	0	2	.125
January 1970	0	0	0	0	0
February 1970	60	3	.050	27	.450
March 1970	48	10	.208	12	.250
April 1970	50	16	.320	33	.660
May 1970	38	15	.395	31	.816
June 1970	28	13	.481	18	.666
July 1970	22	1	.045	10	.454
August 1970	29	6	.207	11	.379
September 1970	19	1	.052	5	.263
October 1970	19	1	.052	8	.421
November 1970	19	6	.315	10	.526
December 1970	19	6	.315	11	.578
January 1971	19	2	.105	4	.210
February 1971	18	1	.055	6	.333

Table 18. Percent Frequency of Occurrence of Male *P. vigil* and *T. crenata* by Section

Section	*Podophthalmus vigil* Percent Male	*Thalamita crenata* Percent Male
I	43%	51%
II	71%	65%
III	67%	74%
IV	---	71%

Table 19. Catch Per Unit Effort of *P. vigil* and *T. crenata* on Incoming and Outgoing Tides

		Podophthalmus vigil		*Thalamita crenata*	
Tide Direction	Nets Set	Number of Crabs Collected	Catch/Unit Effort	Number of Crabs Collected	Catch/Unit Effort
Incoming	235	51	.217	120	.511
Outgoing	158	31	.196	67	.424
Zero	10	0	0	2	.2
Totals	403*	82	.203	189	.469

*5 nets taken with no tide direction noted.

Table 20. Number of Fishes Captured and Distribution of Standard Lengths

	Number of Fish	Mean	Standard Length Median	Range (cm)
Albula vulpes	8	14.65	12.60	6.25-35.00
Apogon brachygrammus	288	3.19	2.96	0.92-5.51
Arothon hispidis	77	9.07	7.85	0.89-20.50
Bathygobius fuscus	32	4.23	4.07	2.16-6.75
Bothus pantherinus	1	12.70	12.70	12.70
Caranx sp.	1	11.65	11.65	11.65
Chanos chanos	25	41.60	43.50	28.00-52.40
Eleotris sandwicensis	27	7.67	8.40	4.00-12.00
Elops hawaiiensis	51	32.03	34.50	6.20-43.00
Mugil cephalus	29	24.70	25.00	10.50-34.00
Oxyurichthys lonchotus	68	5.11	5.52	1.80-7.42
Polydactylus sexfilis	1	9.58	9.58	9.58
Saurida gracilis	18	12.30	13.32	2.93-17.00
Scomberoides sancti-petri	12	26.86	30.00	13.00-35.50
Sphyraena barracuda	14	33.55	36.35	20.00-42.00
Stolephorus purpureus	21	4.97	5.09	3.46-6.52
Tilapia mozambique	26	20.11	20.00	14.00-27.00
Upeneus arge	8	6.66	6.03	3.49-10.20
Vitraria clarescens	1	3.47	3.47	3.47

Table 21. Fish Catch Per Unit Effort Using Otter Trawls and Gill Nets

Species	Otter Trawls No. of Fish	Otter Trawls Catch/Unit Effort	Gill Nets No. of Fish	Gill Nets Catch/Unit Effort
Albula vulpes	7	.13	1	.012
Apogon brachygrammus	288	5.24	---	---
Arothon hispidis	77	1.46	---	---
Bathygobius fuscus	32	.58	---	---
Bothus pantherinus	1	.02	---	-
Caranx sp.	1	.02	---	---
Chanos chanos	---	---	25	.301
Eleotris sandwicensis	27	.49	---	---
Elops hawaiiensis	---	---	48	.578
Mugil cephalus	2	.04	27	.325
Oxyurichthys lonchotus	68	1.236	---	---
Polydactylus sexfilis	1	.02	---	---
Saurida gracilis	18	.33	---	---
Scomberoides sancti-petri	---	---	12	.14
Sphyraena barracuda	6	.11	8	.096
Stolephorus purpureus	21	.38	---	---
Tilapia mozambique	6	.11	20	.240
Upeneus arge	8	.145	---	---
Vitraria clarescens	1	.02	---	---
	No. of Trawls = 55		No. of Gill Nets = 83	

Table 22. **Frequency of Occurrence of Fishes Versus Month for Fishes Caught by Otter Trawl Method**

METHOD 3 OTTER TRAWL	'69 Oct	'69 Nov	'70 Feb	'70 Mar	'70 Apr	'70 May	'70 Jun	'70 Jul	'70 Aug	'70 Sep	'70 Oct	'70 Nov	'70 Dec	'71 Jan	'71 Feb	'71 Mar	'71 Apr
Albula vulpes								2	2			2	1				
Apogon brachygrammus	1	12			5	25	1	6	46	20	48	42	51		29		
Arothon hispidis	3	3	5		1	11	3	8	8	1	7	4	2	10	9	2	
Bathygobius fuscus					2			10		4	3	2	10		1		
Bothus pantherinus							1										
Caranx Sp.										1							
Chanos chanos																	
Eleotris sandwicencis						3	17	1	5					1			
Elops hawaiiensis				1			4		1								
Larval fish															1		
Leptocephalus larvae																	
Mugil cephalus														2			
Oxyurichthus lonchotus		2				11	13	10	5		1		20		6		
Polydactylus sexfilis	1																
Saurida gracilis	1		2		1				4	1	3		5		3		
Scomberoides sancti-petri															1		
Sphyraena barracuda											1			2	3		
Stolephorus purpureus									2	12		5		1		1	
Tilapia mozambique														5	1		
Upeneus arge											1	6	1				
Vitraria clarescens		1															
Number of nets set	1	2	1	2	2	2	4	5	7	4	8	3	5	3	5	1	

Table 23. Frequency of Occurrence of Fishes Versus Month for Fishes Caught by Gill Net Method

METHOD 2 GILL NET	'69 Oct	'69 Nov	'70 Feb	'70 Mar	'70 Apr	'70 May	'70 Jun	'70 Jul	'70 Aug	'70 Sep	'70 Oct	'70 Nov	'70 Dec	'71 Jan	'71 Feb	'71 Mar	'71 Apr
Albula vulpes													1				
Apogon brachygrammus																	
Arothon hispidis																	
Bathygobius fuscus																	
Bothus pantherinus																	
Caranx Sp.																	
Chanos chanos			3				4	3	3	1	6		4		1		
Eleotris sandwicencis																	
Elops hawaiiensis			1		2	1	1	10	4	3	10	5	2	1	2	2	1
Larval fish																	
Leptocephalus larvae																	
Mugil cephalus					4				1	3	1			7	7	4	
Oxyurichthus lonchotus																	
Polydactylus sexfilis																	
Saurida gracilis																	
Scomberoides sancti-petri									1	2	1	2	1	1	2		2
Sphyraena barracuda								2		1	1		2	1	1		
Stolephorus purpureus																	
Tilapia mozambique			2												7	11	
Upeneus arge																	
Vitraria clarescens																	
Number of nets set	0	0	1	0	3	4	6	9	8	9	5	7	7	4	9	5	6

Table 24. Gill Nets: Distribution of Fishes Relative to Tide

Species	IN TIDE - 43 Nets			OUT TIDE - 36 Nets			ZERO TIDE - 4 Nets		
	No. of Fish	No. of Nets	Catch/ Effort	No. of Fish	No. of Nets	Catch/ Effort	No. of Fish	No. of Nets	Catch/ Effort
Albula vulpes	1	1	.02	0	0	0	0	0	0
Chanos chanos	3	3	.07	20	9	.56	2	2	.5
Elops hawaiiensis	17	9	.395	28	12	.78	3	3	.75
Mugil cephalus	15	6	.35	6	2	.17	6	3	1.5
Scomberoides sancti-petri	8	8	.19	3	3	.08	1	1	.25
Sphyraena barracuda	5	4	.12	3	2	.08	0	0	0
Tilapia mozambique	18	3	.42	2	1	.05	0	0	0

Table 25. Otter Trawls: Distribution of Fishes Relative to Tide

Species	IN TIDE - 34 Nets			OUT TIDE - 16 Nets			ZERO TIDE - 5 Nets		
	No. of Fish	No. of Nets	Catch/ Effort	No. of Fish	No. of Nets	Catch/ Effort	No. of Fish	No. of Nets	Catch/ Effort
Albula vulpes	4	3	.12	2	2	.125	1	1	.2
Apogon brachygrammus	154	9	4.53	70	8	4.375	64	4	12.8
Arothon hispidis	33	11	.97	33	12	2.06	11	2	2.2
Bathygobius fuscus	8	3	.24	13	2	.81	11	2	2.2
Eleotris sandwicensis	23	3	.68	3	3	.19	1	1	.2
Mugil cephalus	0	0	0	2	1	.125	0	0	0
Oxyurichthys lonchotus	29	7	.85	15	4	.94	24	3	4.8
Saurida gracilis	7	5	.21	5	4	.31	6	2	1.2
Sphyraena barracuda	0	0	0	5	3	.31	1	1	.2
Stolephorus purpureus	18	3	.53	3	2	.19	0	0	0
Tilapia mozambique	0	0	0	6	2	.375	0	0	0
Upeneus arge	7	2	.21	0	0	0	1	1	.2

APPENDIX B

Figures 1 - 15

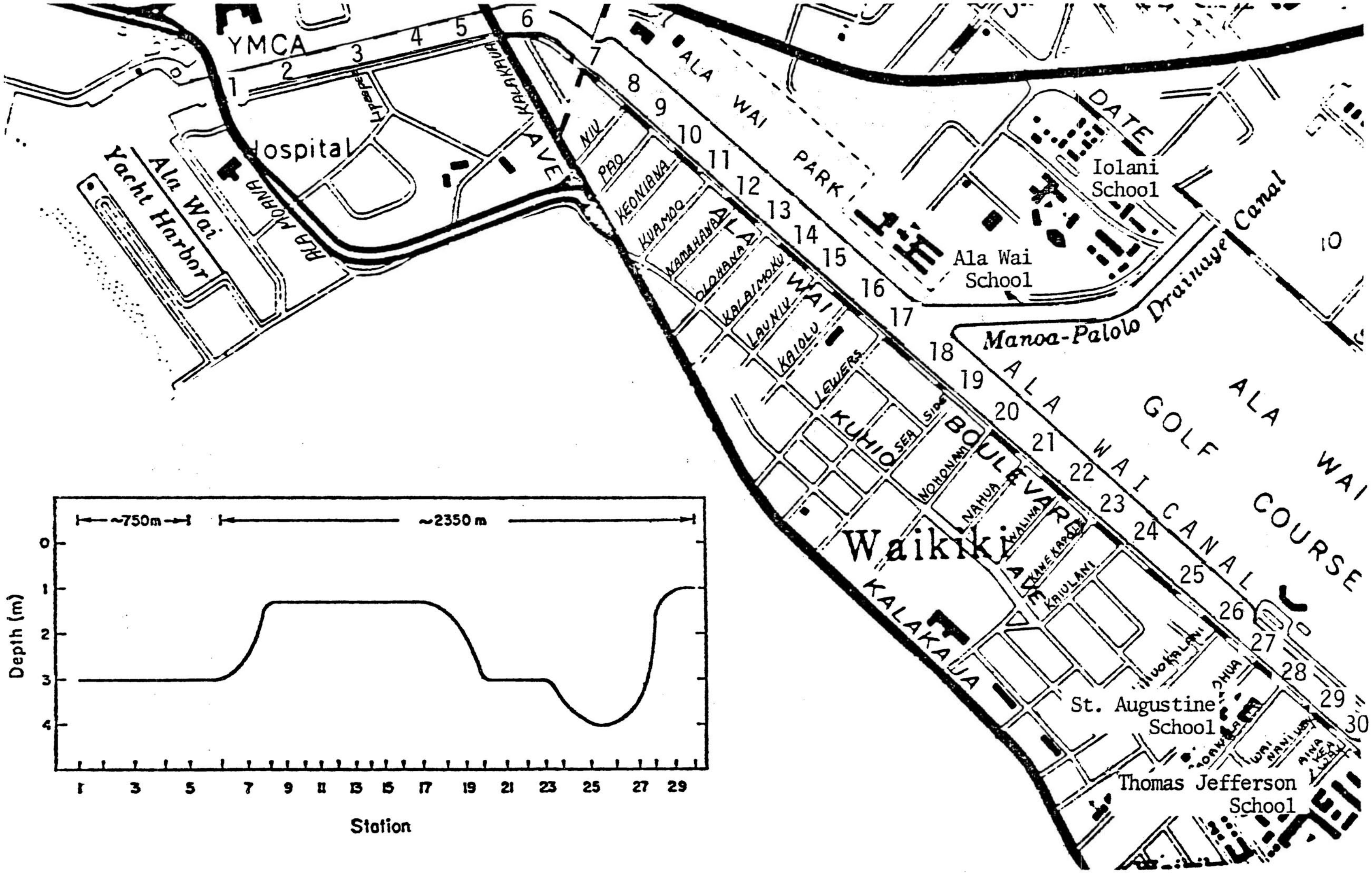

Fig. 1. Ala Wai Canal station locations.

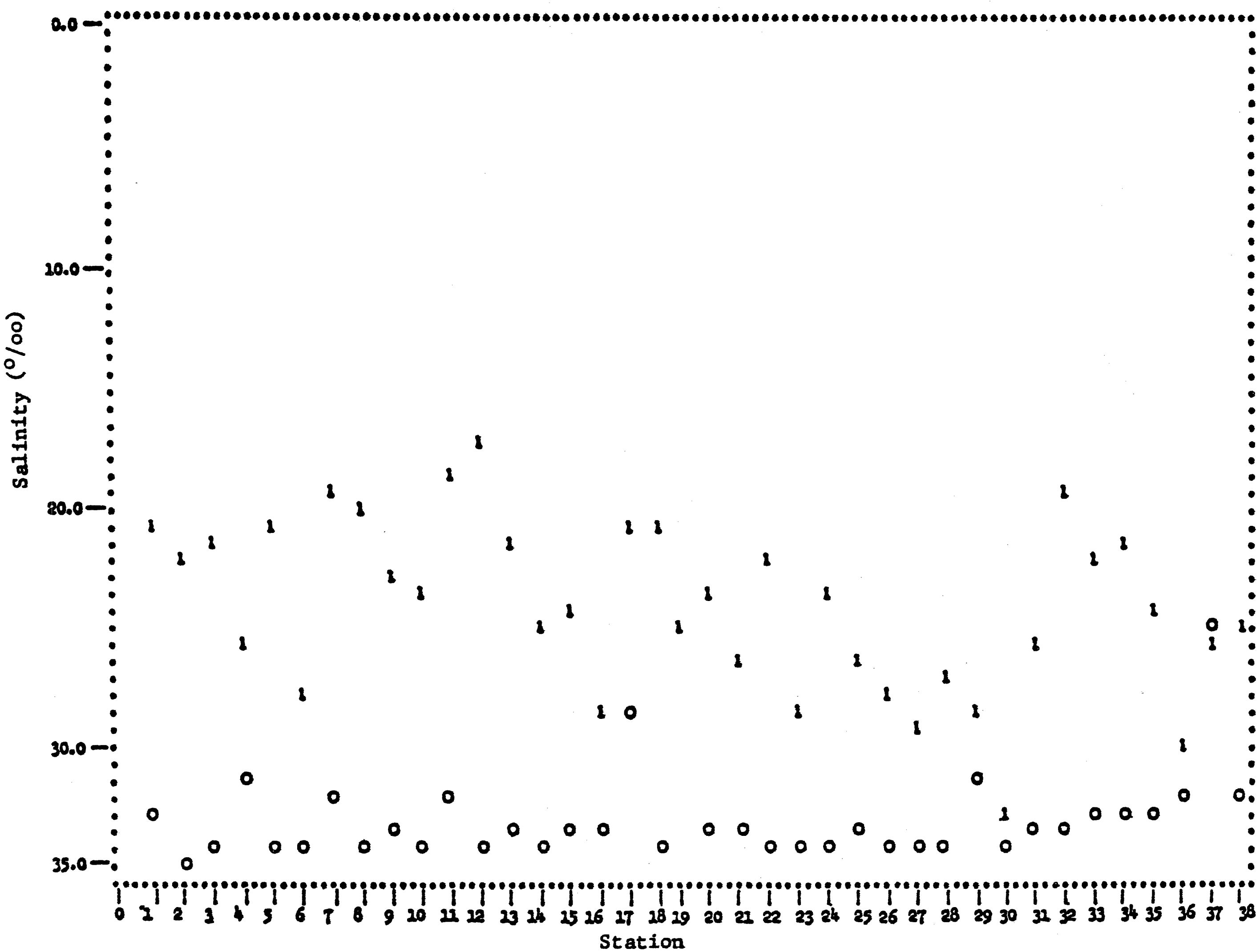

Fig. 2. Average surface (1) and bottom (0) salinity.

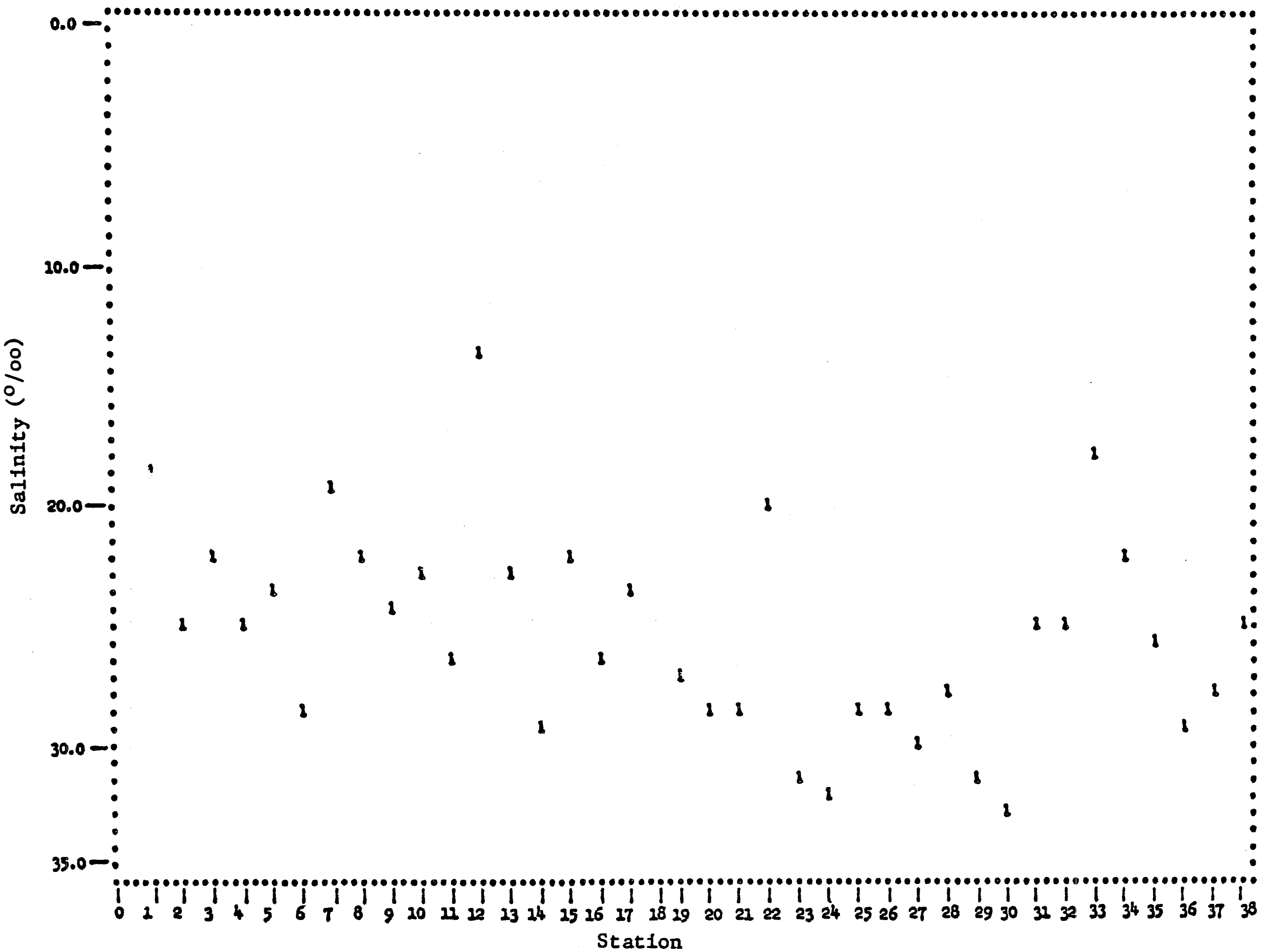

Fig. 3. Average surface salinity on an incoming tide.

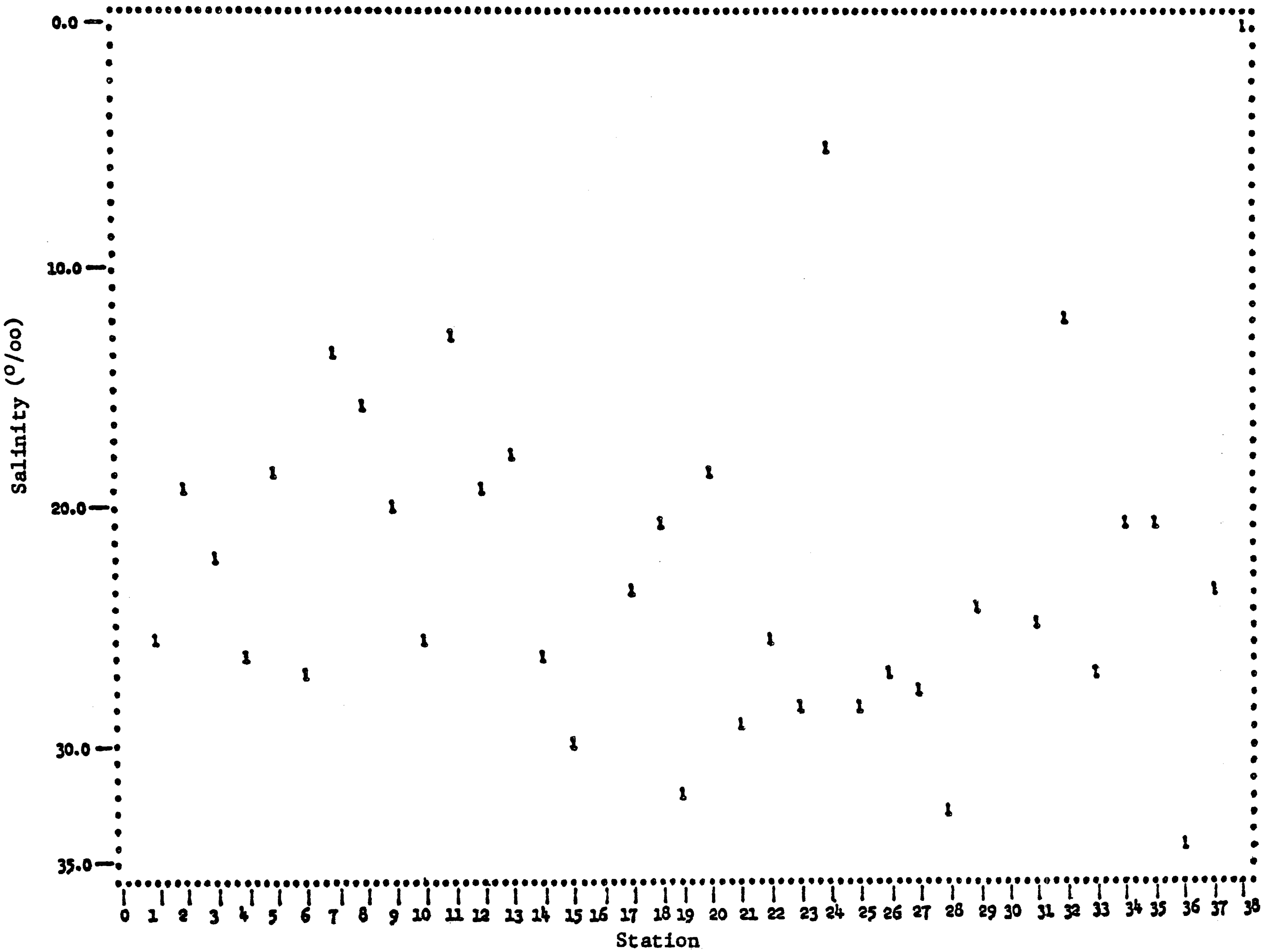

Fig. 4. Average surface salinity on an outgoing tide.

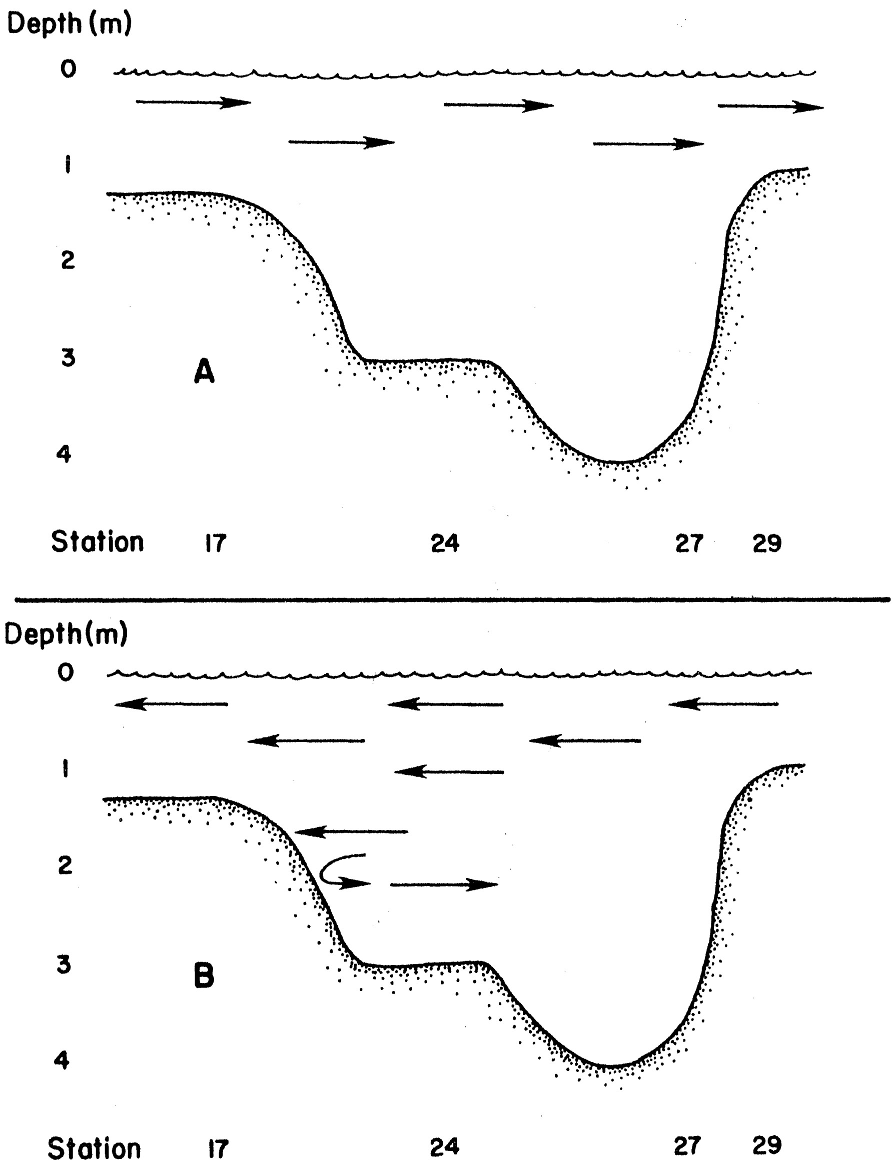

Fig. 5. Direction of flow of surface water, stations 17-29. (A) Incoming tide. (B) Outgoing tide.

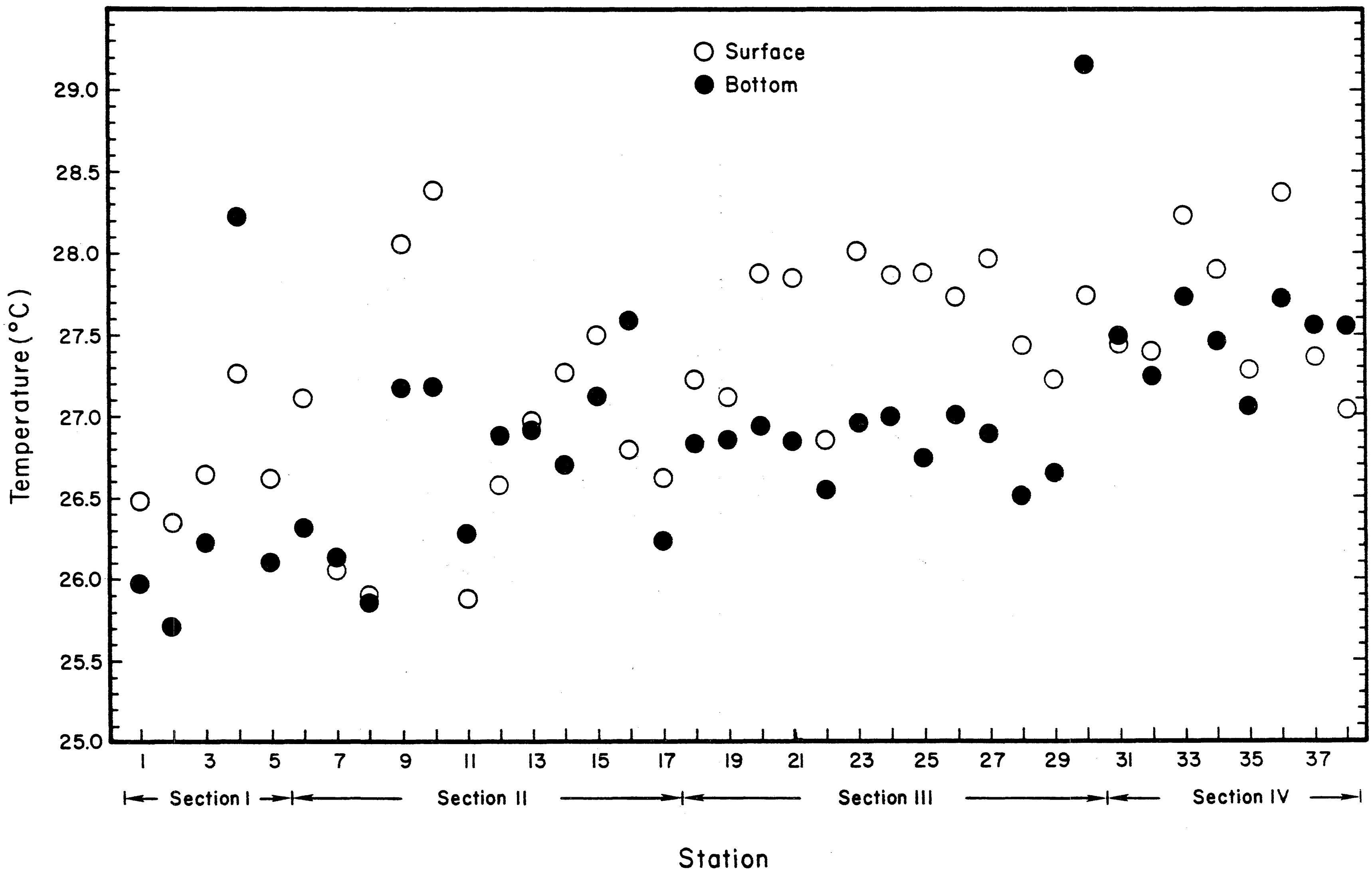

Fig. 6. Mean surface and bottom temperature.

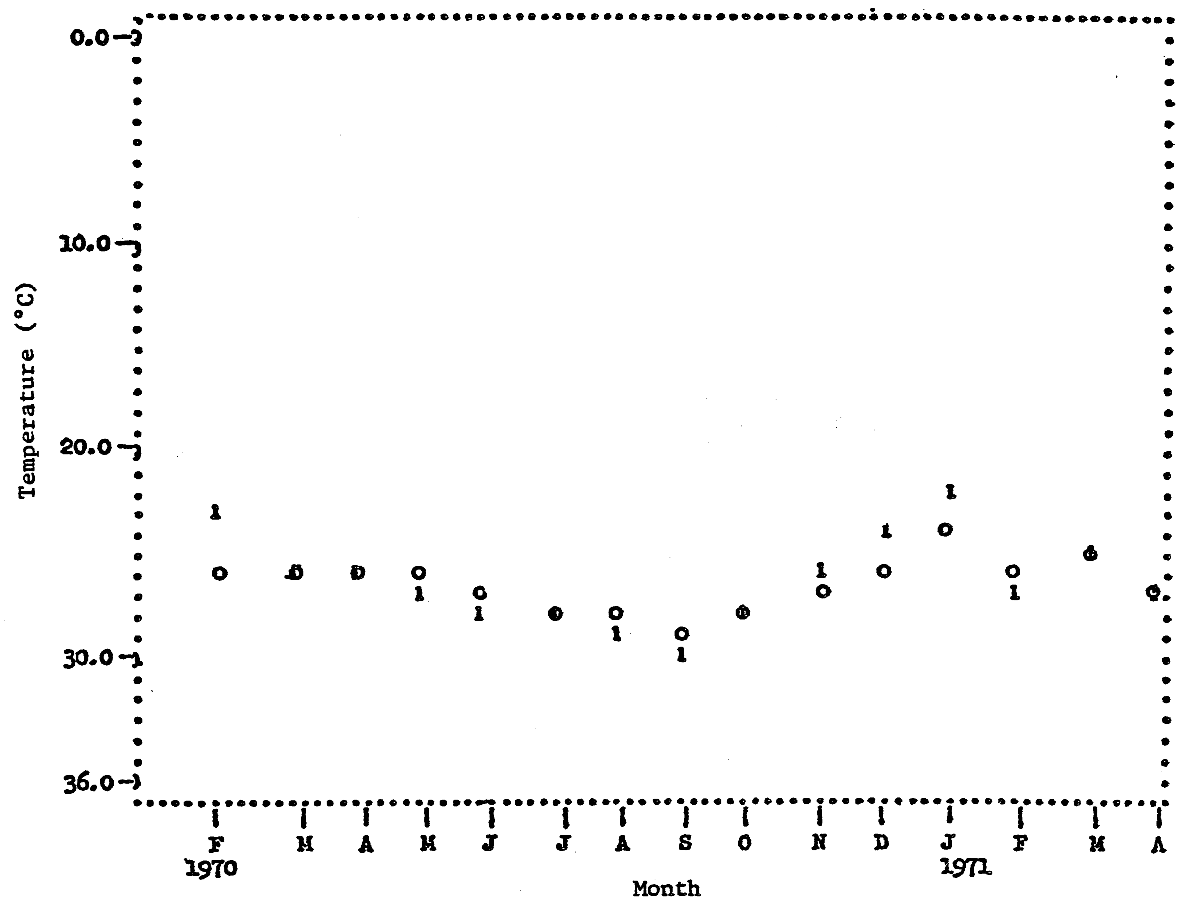

Fig. 7. Surface (1) and bottom (0) temperature data, stations 6-17.

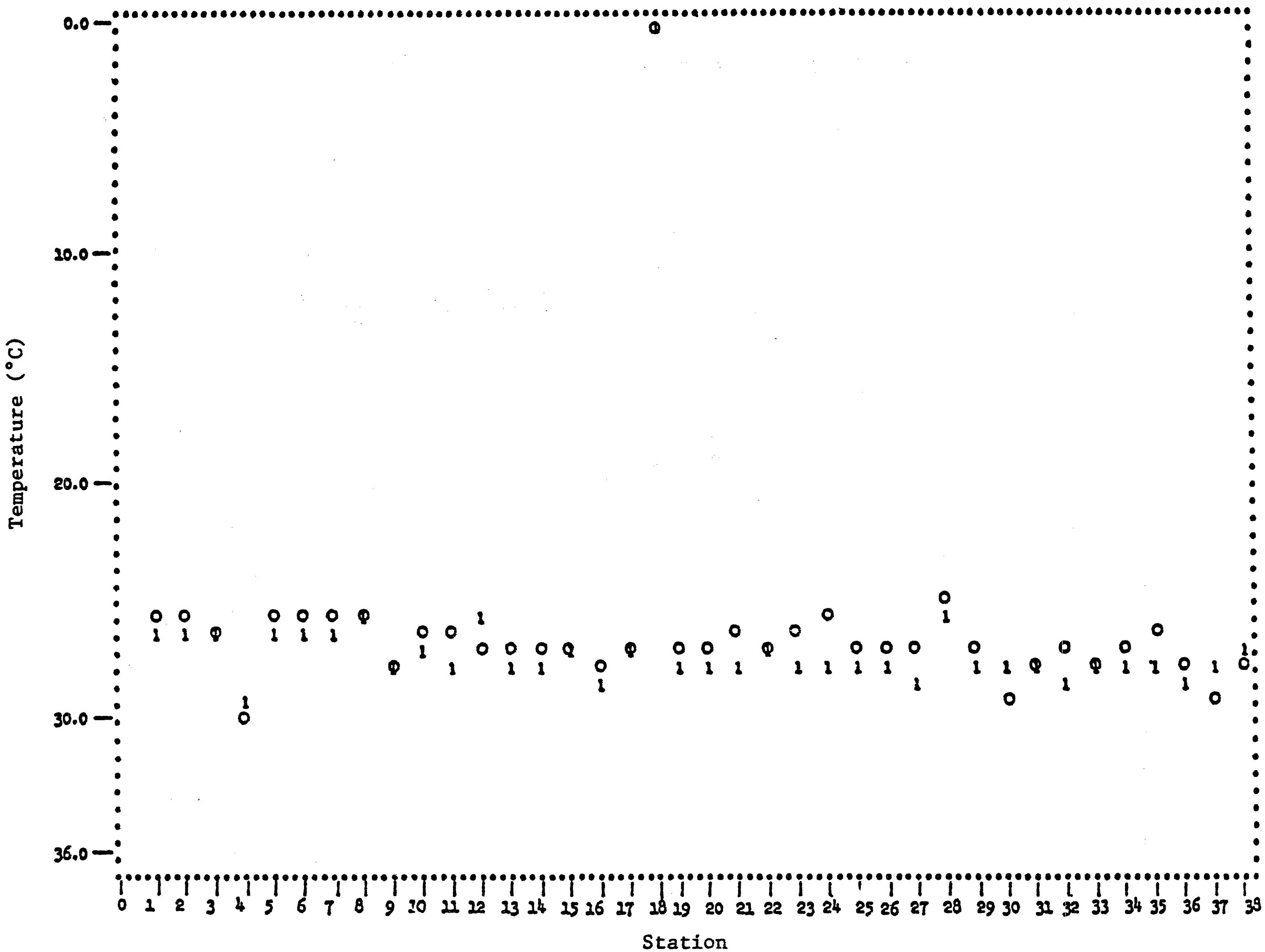

Fig. 8. Average surface (1) and bottom (0) temperature on an incoming tide.

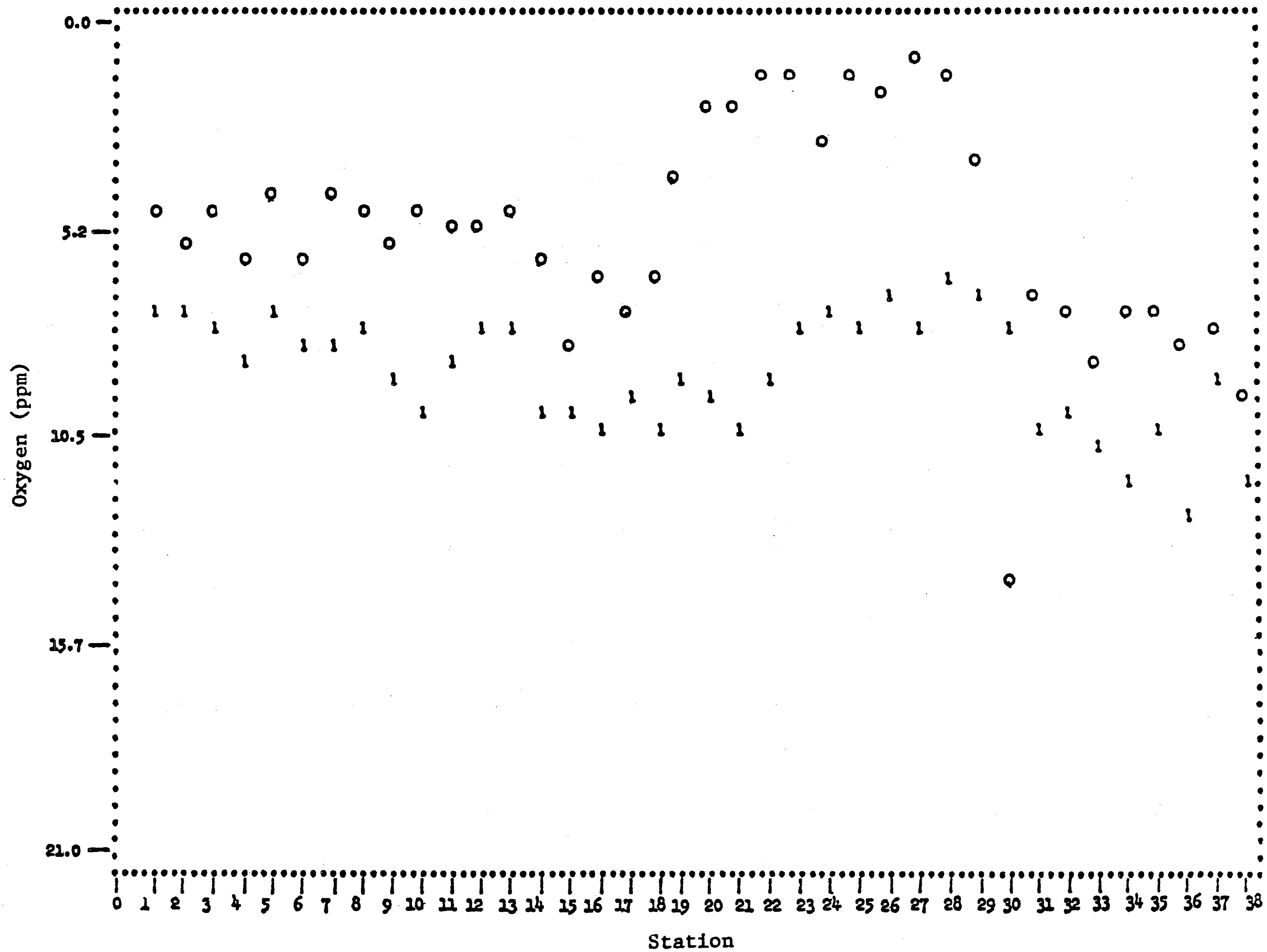

Fig. 9. Average surface (1) and bottom (0) oxygen versus station.

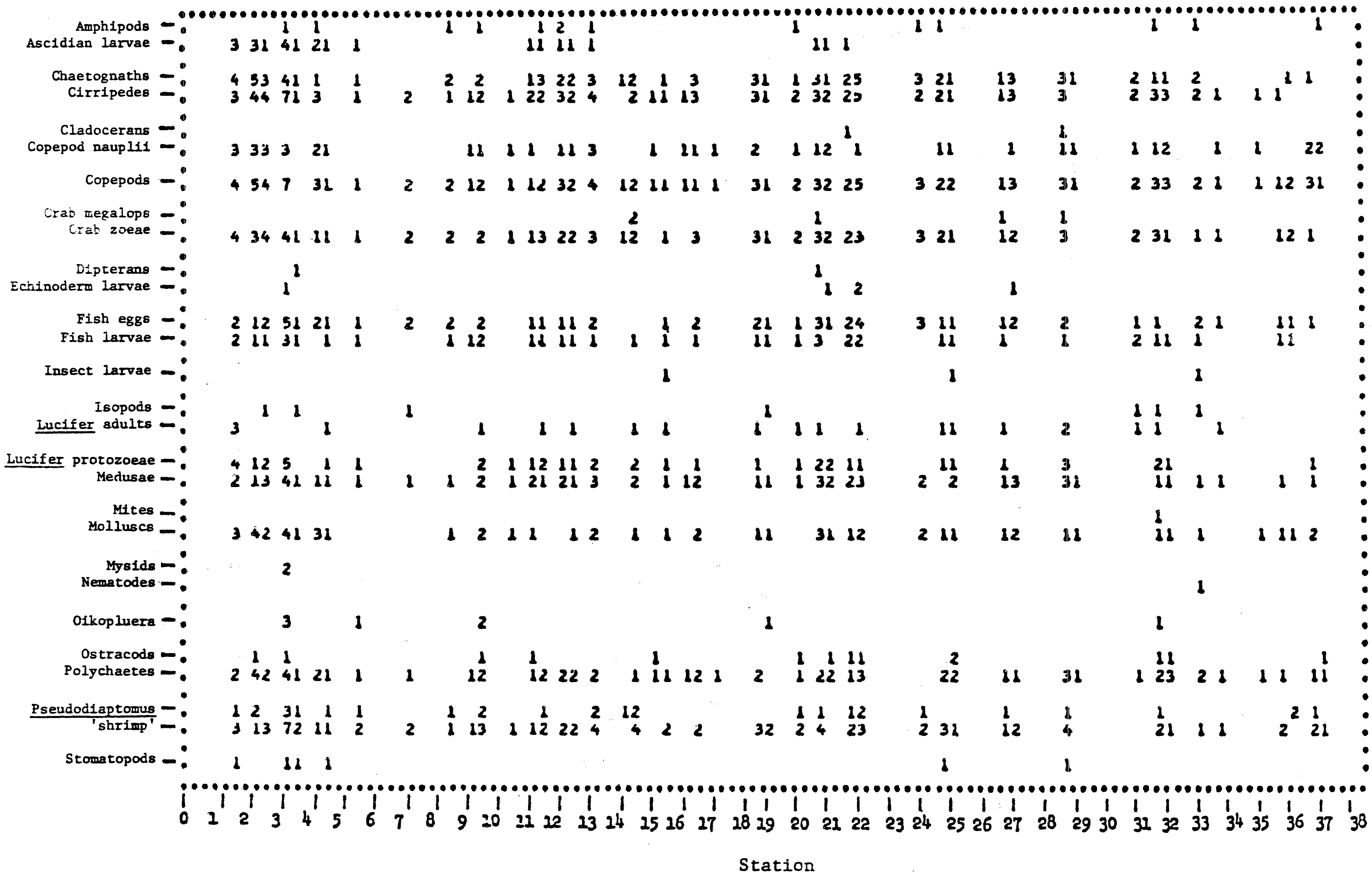

Fig. 10. Number of samples containing each zooplankton species versus station.

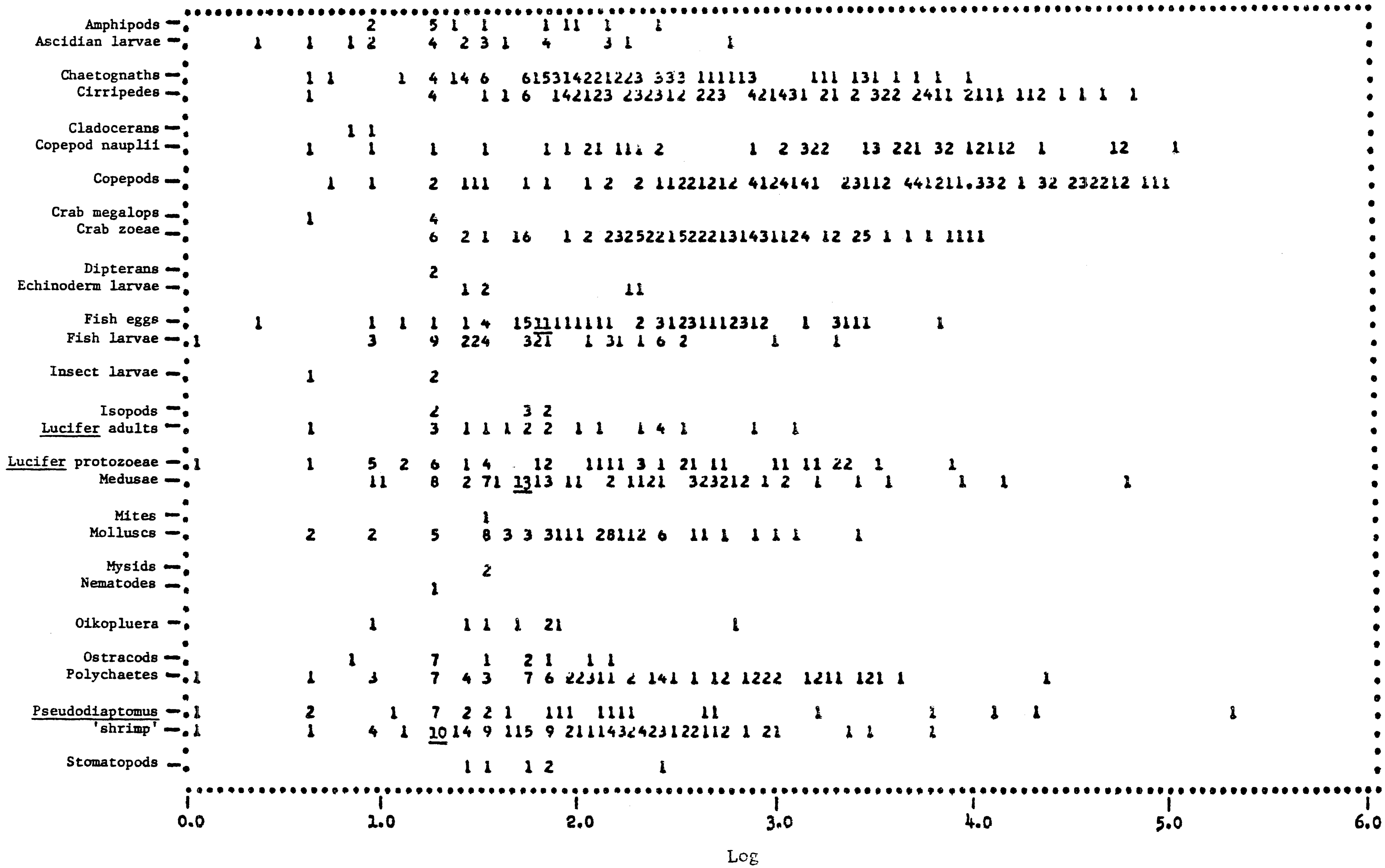

Fig. 11. Zooplankton versus log of total number.

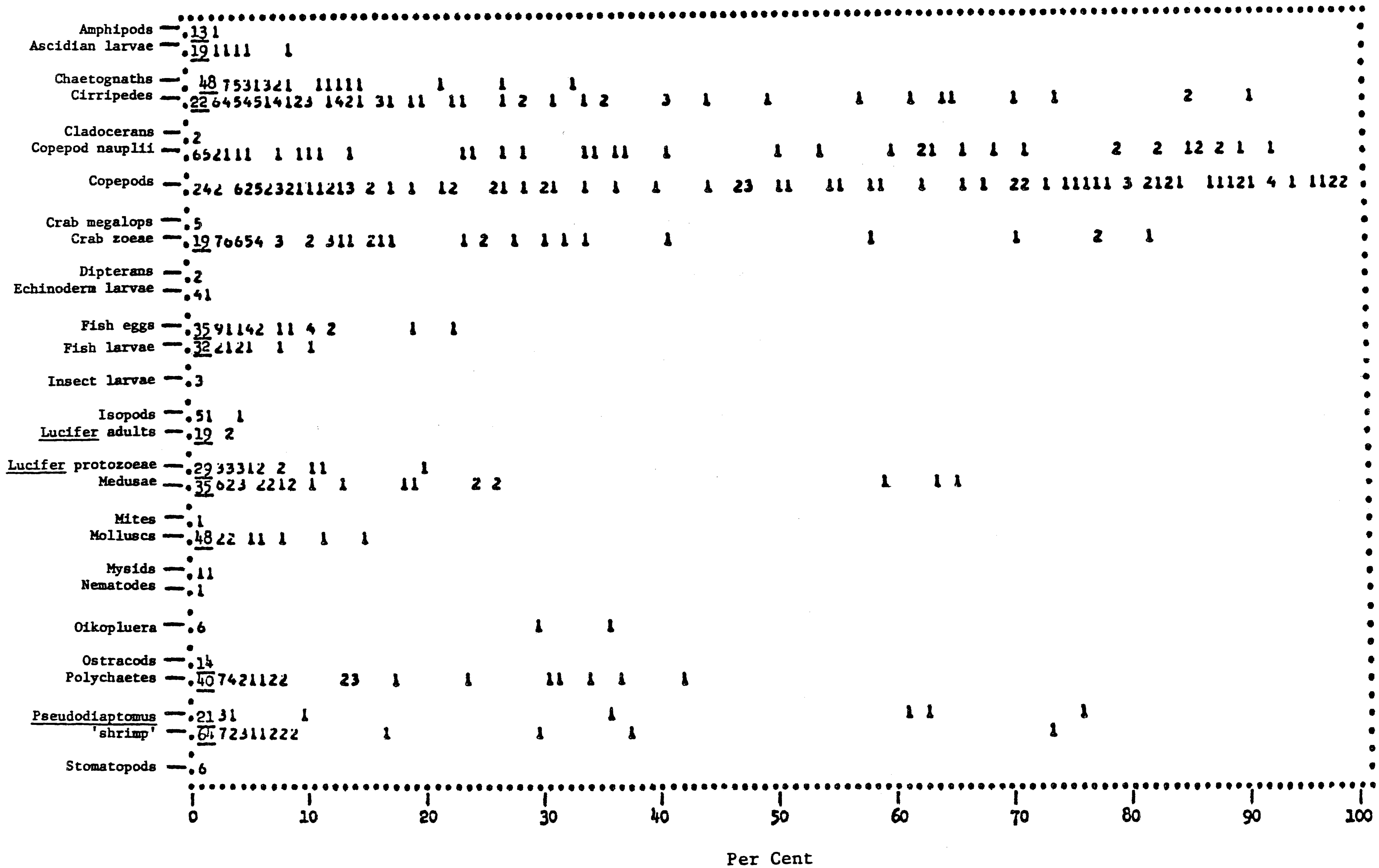

Fig. 12. Number of samples where present and their percent abundance relative to numbers of other species in each sample.

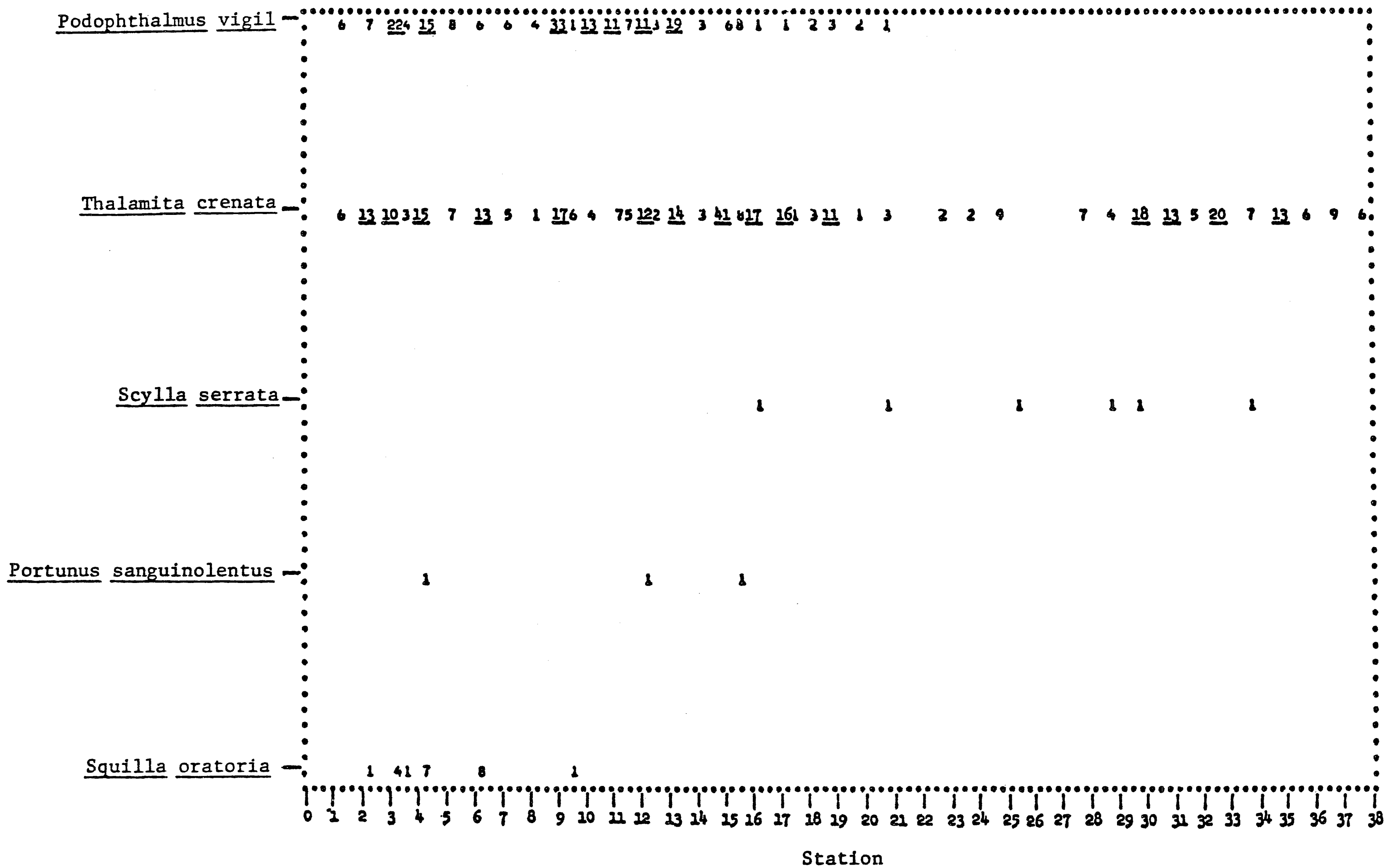

Fig. 13. Distribution of macro crustacea versus station.

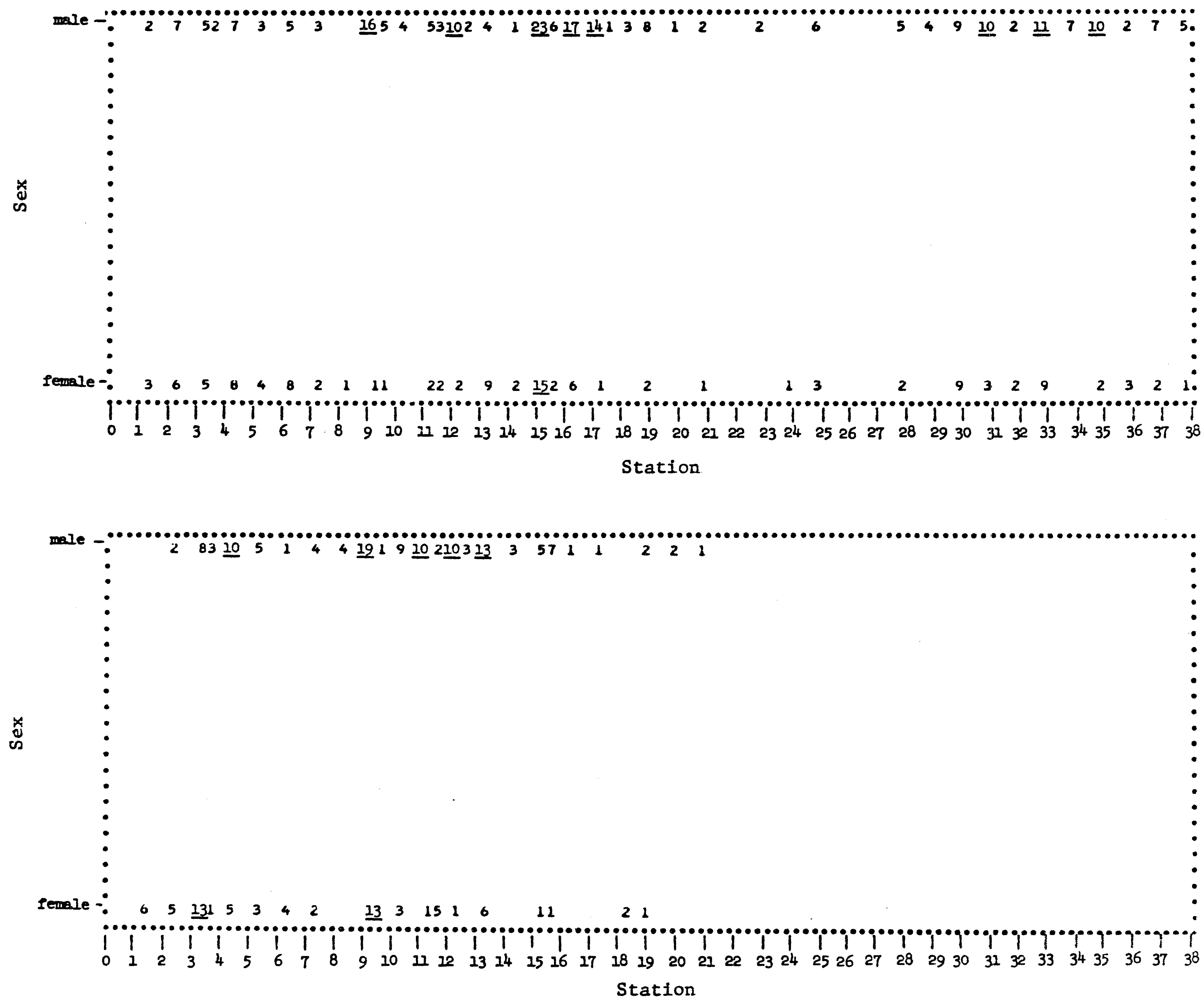

Fig. 14. Sex versus station. (Upper) Thalamita crenata. (Lower) Podophthalmus vigil.

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
<u>A</u>. <u>vulpes</u>			21	1					11									1	2																			
<u>A</u>. <u>brachygrammus</u>		78	112	22		36			32	1	2	1	5		17																							
<u>A</u>. <u>hispidis</u>		3	7	13		2			19	5	6	92	3		3			5			1							2										
<u>B</u>. <u>fuscus</u>			15	14						3																												
<u>B</u>. <u>pantherinus</u>			1																																			
<u>Caranx</u> sp.				1																																		
<u>C</u>. <u>chanos</u>	1											1		1		1		1	2		5				3	2			3		4			1				
<u>E</u>. <u>sandwicensis</u>		1	3						4			11			17																							
<u>E</u>. <u>hawaiiensis</u>	2	6	5		2			1	1			7		1	4	1	3	10		1			1		1		1		1		1	2						
larval fish			1												2																							
<u>L</u>. <u>larvae</u>											2				2																							
<u>M</u>. <u>cephalus</u>		1				1		1	2	4				4		8	4	2										2										
<u>O</u>. <u>lonchotus</u>			24	7					16	1	5	2			5					6					2													
<u>P</u>. <u>sexfilis</u>													1																									
<u>S</u>. <u>gracilis</u>		4	52	1		4			1			1	1		1																							
<u>S</u>. <u>sancti-petri</u>		2	1	2	1				1						1	2		1															1					
<u>S</u>. <u>barracuda</u>			1			2				1		2				2																		1	4	1		
<u>T</u>. <u>mozambique</u>																											1	5	2		11	4				3		
<u>U</u>. <u>arge</u>		1	7																																			
<u>V</u>. <u>clarescens</u>															1																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38

Station

Fig. 15. Horizontal distribution of fishes.